TOTAL MAXIMUM DAILY LOAD (TMDL)

For

pH and Metals

In the

Obey River Watershed (HUC 05130105)

Fentress, Overton & Putnam Counties, Tennessee

FINAL

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DEPARTMENT OF ENVIRONMENT & CONSERVATION

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LIST OF ABBREVIATIONS

AMD	Acid Mine Drainage
CCC	Criteria Continuous Concentration
CFR	Code of Federal regulations
CFS	Cubic Feet per Second
CMC	Criteria Maximum Concentration
DEM	Digital Elevation Model
DWPC	Division of Water Pollution Control
EPA	Environmental Protection Agency
GIS	Geographic Information System
HUC	Hydrologic Unit Code
ITRC	Instream Total Recoverable Concentration
LA	Load Allocation
LDC	Load Duration Curve
LSPC	Loading Simulation Program in C^{++}
MGD	Million Gallons per Day
MOS	Margin of Safety
MRLC	Multi-Resolution Land Characteristic
NHD	National Hydrography Dataset
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
RM	River Mile
TDEC	Tennessee Department of Environment & Conservation
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WCS	Watershed Characterization SYstem
WLA	Waste Load Allocation

SUMMARY SHEET

Total Maximum Daily Load (TMDL) for pH and Metals in Obey River Watershed (05130105)

Impaired Waterbody Information

State: Tennessee
Counties: Fentress, Overton, and Putnam
Watershed: Obey River (HUC 05130105)
Constituents of Concern: pH and metals (aluminum, arsenic, cadmium, chromium, copper, lead, manganese, nickel, and zinc)

Impaired Waterbodies Addressed in This Document:

Waterbody ID	Waterbody	Miles Impaired
TN05130105015 – 0300	CUB CREEK	7.2
TN05130105015 – 2000	WEST FORK OBEY RIVER	13.1
TN05130105019 – 1100	BIG LAUREL CREEK	9.2
TN05130105019 – 1110	LITTLE LAUREL CREEK	3.6
TN05130105019 – 1200	BIG PINEY CREEK	18.6
TN05130105019 – 2000	EAST FORK OBEY RIVER	22.6
TN05130105019 – 3000	EAST FORK OBEY RIVER	11.1

Designated Uses:

The designated use classifications for waterbodies in the Obey River Watershed include fish and aquatic life, irrigation, livestock watering & wildlife, and recreation. East Fork Obey River (Mile 0.0 to headwaters) is also designated for domestic water supply.

Water Quality Targets:

Derived from *State of Tennessee Water Quality Standards, Chapter 1200-4-3, General Water Quality Criteria, January, 2004*:

The pH value shall lie within the range of 6.0 to 9.0 and shall not fluctuate more than 1.0 unit in this range over a period of 24 hours.

Derived from *National Recommended Water Quality Criteria (USEPA, 2006)*:

Iron, total 1000 μg/L

Tennessee does not have a numeric water quality criterion for iron. However, TDEC believes that meeting the above criteria will satisfy the requirement that "waters shall not contain substances or a combination of substances including disease-causing agents which, by way of either direct exposure or indirect exposure through food chains, may cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), physical deformations, or restrict of impair growth in fish or aquatic life or their offspring".

Derived from *Secondary maximum contaminant levels, 40 CFR Part 143.3,* for public water systems:

Iron	300 μg/L
Manganese	50 μg/L
Aluminum	50-200 μg/L

For Cub Creek, which is not designated for drinking water supply, there is not a specific numeric target for manganese. TDEC believes that meeting the water quality criteria for pH (and its surrogate net alkalinity) and iron will also ensure that Cub Creek is no longer impaired for manganese.

Water quality criteria for cadmium, chromium, copper, lead, nickel, and zinc for waterbodies classified for fish & aquatic life are a function of total hardness. (See Appendix D.)

TMDL Scope:

Waterbodies identified on the Final 2006 303(d) list as impaired due to pH and metals.

Portions of the Obey River watershed are located in Kentucky. This TMDL only addresses the portion of the Obey River watershed located in Tennessee.

Analysis of monitoring data for West Fork Obey River suggests that it is no longer impaired for pH, iron, manganese, cadmium, chromium, copper, lead, nickel, and zinc. At this time, de-listing is suggested for pH and "metals".

Analysis of monitoring data for East Fork Obey River suggests that it is still impaired for pH, aluminum, iron, and manganese. At this time, de-listing is suggested for "metals" and listing is suggested for aluminum, iron, and manganese for segmentsTN05130104019 –2000 and -3000. Based on analysis of monitoring data for monitoring station EFOBE012.6FE, TDEC also suggests listing of segment TN05130104019–1000 for aluminum, iron, and manganese.

Monitoring data was unavailable for Cub Creek, Big Piney Creek, Big Laurel Creek, and Little Laurel Creek. Additional monitoring is recommended to either confirm impairment or allow for delisting.

Analysis/Methodology:

Net alkalinity was used as a surrogate for pH. The net alkalinity TMDL for impaired waterbodies in the Obey River Watershed was developed using a load duration curve methodology to assure compliance with the target net alkalinity of 10.8 mg/L (see Appendices C & E), which will provide a pH within the criteria range of 6.0 – 9.0. A duration curve is a cumulative frequency graph that represents the percentage of time during which the value of a given parameter is equaled or exceeded. Load duration curves are developed from flow duration curves and can illustrate existing water quality conditions (as represented by loads calculated from monitoring data), how these conditions compare to desired targets, and the region of the waterbody flow regime represented by these existing loads.

The TMDLs for aluminum, iron, and manganese also were developed using load duration curves for analysis of impaired subwatersheds. The TMDLs, WLAs, and LAs for net alkalinity and each metal are summarized in the following table.

Hardness-dependent criteria were developed for cadmium, chromium, copper, lead, nickel, and zinc using available monitoring data (see Appendix D). Analysis of monitoring data for East Fork and West Fork Obey River indicated no exceedances of the criteria. Therefore, no TMDLs were developed for these six metals.

Critical Conditions:

Water quality data collected over a period of 10 years for load duration curve analysis were used to assess the water quality standards representing a range of hydrologic and meteorological conditions.

Seasonal Variation:

The 10-year period used for LSPC model simulation period for development of load duration curve analysis included all seasons and a full range of flow and meteorological conditions.

Margin of Safety (MOS):

Implicit (conservative modeling assumptions) and explicit (10% of the water quality criteria for each individual metal for each impaired subwatershed).

Summary of TMDLs, WLAs, & LAs expressed as daily loads for Impaired Waterbodies in the Obey River Watershed (HUC 05130105)

Impaired Waterbody Name	Impaired Waterbody ID	Constituent	TMDL [lbs/day]	Explicit MOS [lbs/day]	WLAs [lbs/day]	LAs [lbs/day/ac]
Cub Creek	TN05130105015 – 0300	Net Alkalinity	58.1 x Q	NA[a]	NA	$1.56 \times 10^{-2} \times Q$
		Iron	5.38 x Q	0.538 x Q	NA	$1.30 \times 10^{-3} \times Q$
West Fork Obey River	TN05130105015 – 2000	Net Alkalinity	58.1 x Q	NA[a]	NA	$1.33 \times 10^{-3} \times Q$
		Iron	5.38 x Q	0.538 x Q	NA	$1.10 \times 10^{-4} \times Q$
Big Laurel Creek	TN05130105019 – 1100	Net Alkalinity	58.1 x Q	NA[a]	NA	$7.20 \times 10^{-3} \times Q$
		Iron	5.38 x Q	0.538 x Q	NA	$6.00 \times 10^{-4} \times Q$
Little Laurel Creek	TN05130105019 – 1110	Net Alkalinity	58.1 x Q	NA[b]	NA	$2.39 \times 10^{-2} \times Q$
		Iron	5.38 x Q	0.538 x Q	NA	$1.99 \times 10^{-3} \times Q$
Big Piney Creek	TN05130105019 – 1200	Net Alkalinity	58.1 x Q	NA[a]	NA	$6.11 \times 10^{-3} \times Q$
East Fork Obey River	TN05130105019 – 2000	Net Alkalinity	58.1 x Q	NA[a]	$58.1 \times Q_2$	$(5.36 \times 10^{-4} \times Q) – (5.36 \times 10^{-4} \times Q_2)$
		Iron	1.61 x Q	0.161 x Q	$16.1 \times Q_2$	$(1.34 \times 10^{-5} \times Q) – (1.49 \times 10^{-4} \times Q_2)$
		Manganese	0.269 x Q	$2.69 \times 10^{-2} \times Q$	$10.8 \times Q_2$	$(2.23 \times 10^{-6} \times Q) – (9.93 \times 10^{-5} \times Q_2)$
		Aluminum	1.076 x Q	0.1076 x Q	NA	$4.46 \times 10^{-5} \times Q$
East Fork Obey River	TN05130105019 – 3000	Net Alkalinity	58.1 x Q	NA[a]	NA	$2.68 \times 10^{-3} \times Q$
		Iron	1.61 x Q	0.161 x Q	NA	$6.69 \times 10^{-5} \times Q$
		Manganese	0.269 x Q	$2.69 \times 10^{-2} \times Q$	NA	$1.12 \times 10^{-5} \times Q$
		Aluminum	1.076 x Q	0.1076 x Q	NA	$4.46 \times 10^{-5} \times Q$

Notes: NA = Not Applicable.
NR = No Reduction Required
Q = Mean Daily In-stream Flow (cfs).
Q_2 = Mean Daily Flow (cfs) from Permitted Point Sources (combined)

a. For development of net alkalinity TMDLs, an implicit MOS was incorporated through the use of conservative modeling assumptions (see Section 7.5).

pH and METALS TOTAL MAXIMUM DAILY LOAD (TMDL) OBEY RIVER WATERSHED (HUC 05130105)

1.0 INTRODUCTION

Section 303(d) of the Clean Water Act requires each state to list those waters within its boundaries for which technology based effluent limitations are not stringent enough to protect any water quality standard applicable to such waters. Listed waters are prioritized with respect to designated use classifications and the severity of pollution. In accordance with this prioritization, states are required to develop Total Maximum Daily Loads (TMDLs) for those water bodies that are not meeting designated uses. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions, so that states can establish water quality based controls to reduce pollution from both point and non-point sources and restore and maintain the quality of their water resources (USEPA, 1991a).

2.0 WATERSHED DESCRIPTION

The Obey River Watershed (HUC 05130105) is located in middle and eastern Tennessee and Kentucky (Figure 1). This document addresses only the portion of the watershed located in Tennessee. The Obey River Watershed falls within two Level III ecoregions (Southwestern Appalachians and Interior Plateau) and contains four Level IV subecoregions (USEPA, 1997) as shown in Figure 2:

- **Cumberland Plateau (68a)** tablelands and open low mountains are about 1000 feet higher than the Eastern Highland Rim (71g) to the west, and receive slightly more precipitation with cooler annual temperatures than the surrounding lower-elevation ecoregions. The plateau surface is less dissected with lower relief compared to the Cumberland Mountains (69d) or the Plateau Escarpment (68c). Elevations are generally 1200-2000 feet, with the Crab Orchard Mountains reaching over 3000 feet. Pennsylvanian-age conglomerate, sandstone, siltstone, and shale is covered by well-drained, acid soils of low fertility. Bituminous coal that has been extensively surface and underground mined underlies the region. Acidification of first and second order streams is common. Stream siltation and mine spoil bedload deposits continue as long-term problems in these headwater systems. Pockets of severe acid mine drainage persist.

- **Plateau Escarpment (68c)** is characterized by steep, forested slopes and high velocity, high gradient streams. Local relief is often 1000 feet or more. The geologic strata include Mississippian-age limestone, sandstone, shale, and siltstone, and Pennsylvanian-age shale, siltstone, sandstone, and conglomerate. Streams have cut down into the limestone, but the gorge talus slopes are composed of colluvium with huge angular, slabby blocks of sandstone. Vegetation community types in the ravines and gorges include mixed oak and chestnut oak on the upper slopes, mesic forests on the middle and lower slopes (beech-tulip poplar, sugar maple-basswood-ash-buckeye), with hemlock along rocky streamsides and river birch along floodplain terraces.

- **Eastern Highland Rim (71g)** has level terrain, with landforms characterized as tablelands of moderate relief and irregular plains. Mississippian-age limestone, chert, shale and dolomite predominate, and karst terrain sinkholes and depressions are especially noticeable between Sparta and McMinnville. Numerous springs and spring-associated fish fauna also typify the region. Natural vegetation for the region is transitional between the oak-hickory type to the west and the mixed mesophytic forests of the Appalachian ecoregions to the east. Bottomland hardwoods forests were once abundant in some areas, although much of the original bottomland forest has been inundated by several large impoundments. Barrens and former prairie areas are now mostly oak thickets or pasture and cropland.

- **Outer Nashville Basin (71h)** is a heterogeneous region, with rolling and hilly topography and slightly higher elevations. The region encompasses most all of the outer areas of the generally no-cherty Mississippian-age formations, and some Devonian-age Chattanooga shale, remnants of the Highland Rim. The region's limestone rocks and soils are high in phosphorus, and commercial phosphate is mined. Deciduous forest with pasture and cropland are the dominant land covers. Streams are low to moderate gradient, with productive, nutrient-rich waters, resulting in algae, rooted vegetation and occasionally high densities of fish. The Nashville Basin as a whole has a distinctive fish fauna, notable for fish that avoid the region, as well as those that are present.

The Obey River Watershed, located in Clay, Cumberland, Fentress, Overton, Pickett, and Putnam Counties, Tennessee, has a drainage area of approximately 782 square miles (mi^2) in Tennessee. The entire watershed, including portions of Tennessee and Kentucky, drains approximately 945 square miles. Watershed land use distribution is based on the Multi-Resolution Land Characteristic (MRLC) databases derived from Landsat Thematic Mapper digital images from the period 1990-1993. Although changes in the land use of the Obey River Watershed have occurred since 1993 as a result of development, this is the most current land use data available. Land use for the Obey River Watershed is summarized in Table 1 and Figure 3.

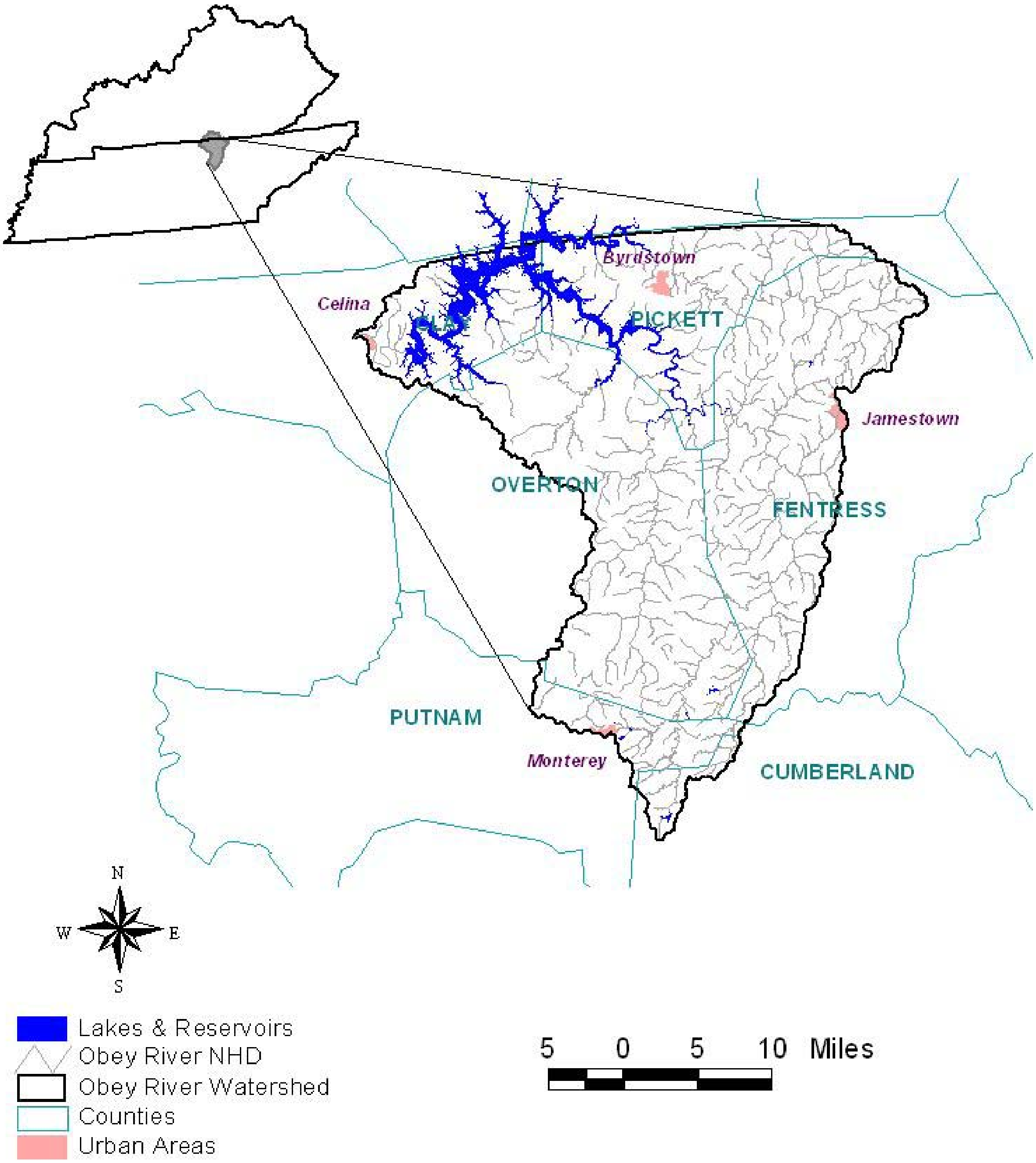

Figure 1 Location of Obey River Watershed

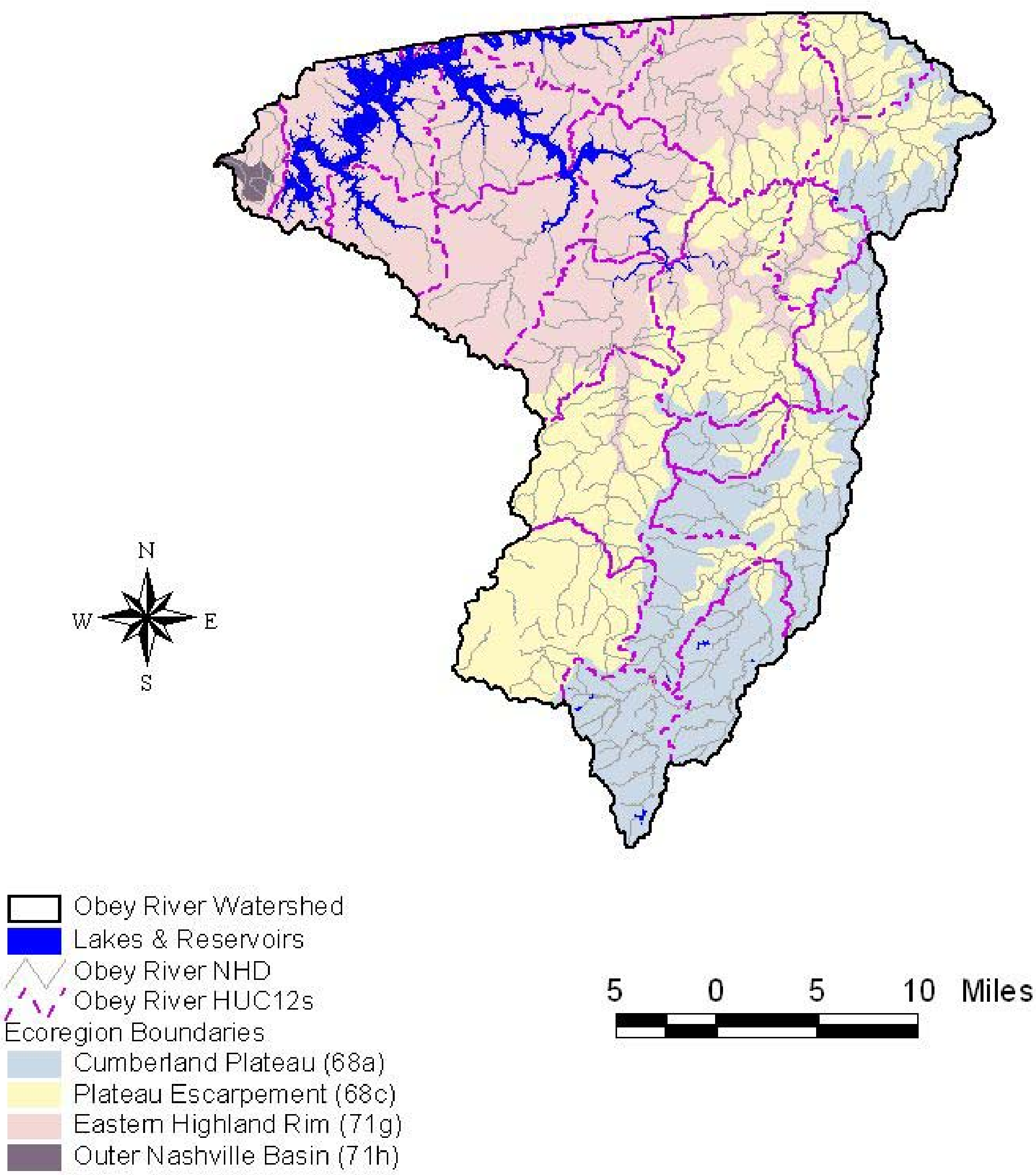

Figure 2 Obey River Watershed Ecoregion Designation

Table 1. MRLC Land Use Distribution – Obey River Watershed (Tennessee portion)

Land Use	Area	
	[acres]	[%]
Bare Rock/Sand/Clay	8	0.0
Deciduous Forest	312,187	62.4
Emergent Herbaceous Wetlands	58	0.0
Evergreen Forest	26,036	5.2
High Intensity Commercial/Industrial/ Transportation	1,070	0.2
High Intensity Residential	80	0.0
Low Intensity Residential	1,922	0.4
Mixed Forest	74,610	14.9
Open Water	19,880	4.0
Other Grasses (Urban/recreational)	1,788	0.4
Pasture/Hay	51,178	10.2
Quarries/Strip Mines/ Gravel Pits	467	0.1
Row Crops	9,559	1.9
Transitional	1,015	0.2
Woody Wetlands	681	0.1
Total	**500,539**	**100.0**

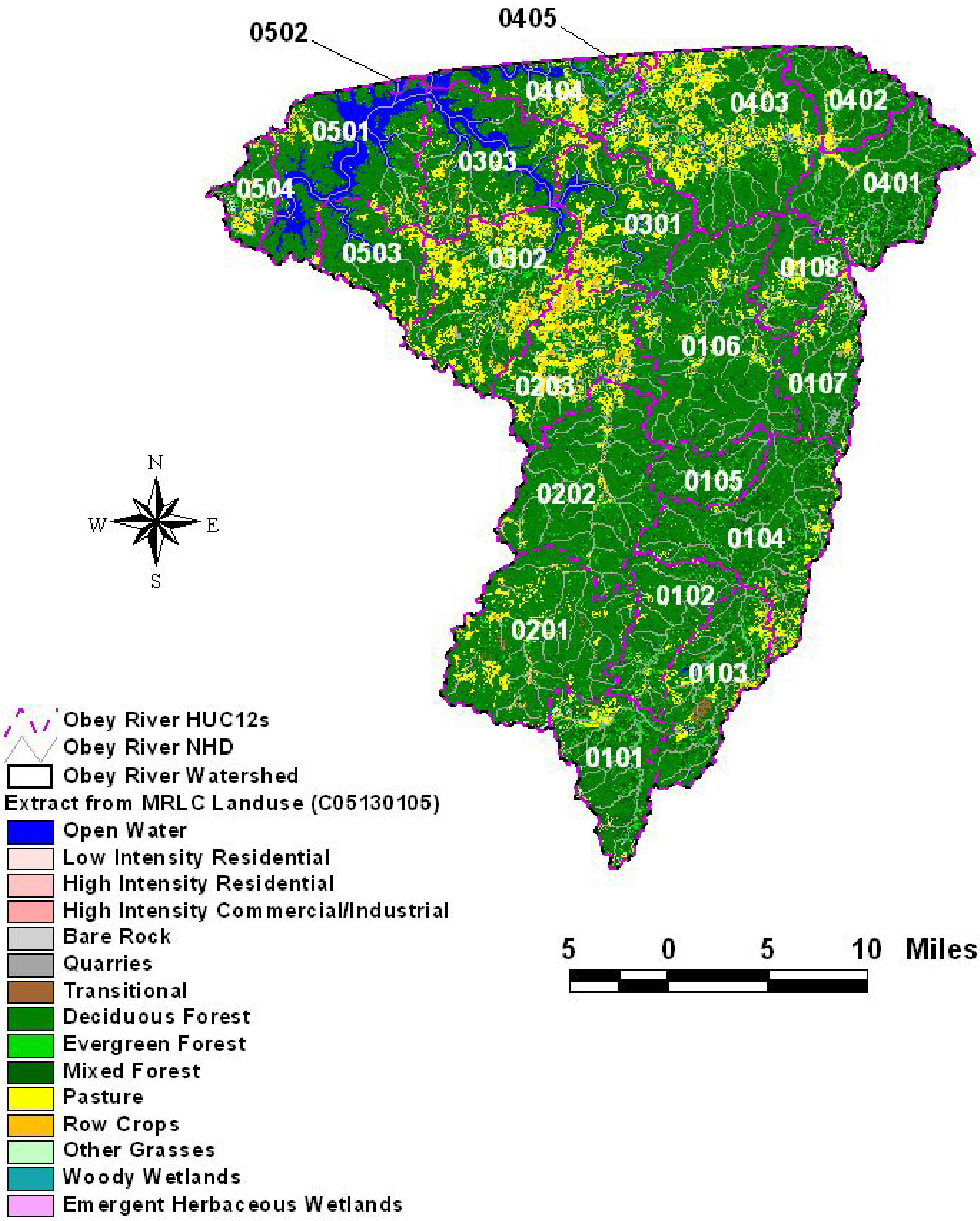

Figure 3 Obey River Watershed Land Use Distribution

3.0 PROBLEM DEFINITION

The State of Tennessee's final 2006 303(d) list (TDEC, 2006) was approved by the U.S. Environmental Protection Agency (EPA), Region IV in October of 2006. The list identified several waterbodies in the Obey River watershed as not supporting designated use classifications due, in part, to pH and metals associated with abandoned mines and resource extraction. Information regarding formation of acid mine drainage (AMD) is contained in Appendix A. An excerpt from the 2006 303(d) list is presented in Table 2. There are several permitted mines in the East Fork Obey River portion of the Obey River watershed. Impaired segments in the Obey River Watershed are shown in Figure 4.

Table 2 2006 303(d) List – Obey River Watershed

Waterbody ID	Impacted Waterbody	County	Miles/Acres Impaired	Cause	Pollutant Source
TN05130105 015 – 0300	Cub Creek	Overton	7.2	Manganese Iron pH	Abandoned Mining
TN05130105 015 – 2000	West Fork Obey River	Overton	13.1	Metals pH Loss of biological integrity due to siltation	Abandoned Mining
TN05130105 019 – 1100	Big Laurel Creek	Fentress Overton	9.2	Iron pH	Abandoned Mining
TN05130105 019 – 1110	Little Laurel Creek	Fentress Overton	3.6	Iron pH	Abandoned Mining
TN05130105 019 – 1200	Big Piney Creek	Fentress Overton	18.6	pH Loss of biological integrity due to siltation	Resource Extraction
TN05130105 019 – 2000	East Fork Obey River	Fentress Overton	22.6	Metals pH Loss of biological integrity due to siltation	Resource Extraction
TN05130105 019 – 3000	East Fork Obey River	Putnam Overton	11.1	Metals pH Loss of biological integrity due to siltation	Resource Extraction

The designated use classifications for East Fork and West Fork Obey River and their tributaries include fish and aquatic life, irrigation, livestock watering & wildlife, and recreation. East Fork Obey River is also designated for domestic water supply.

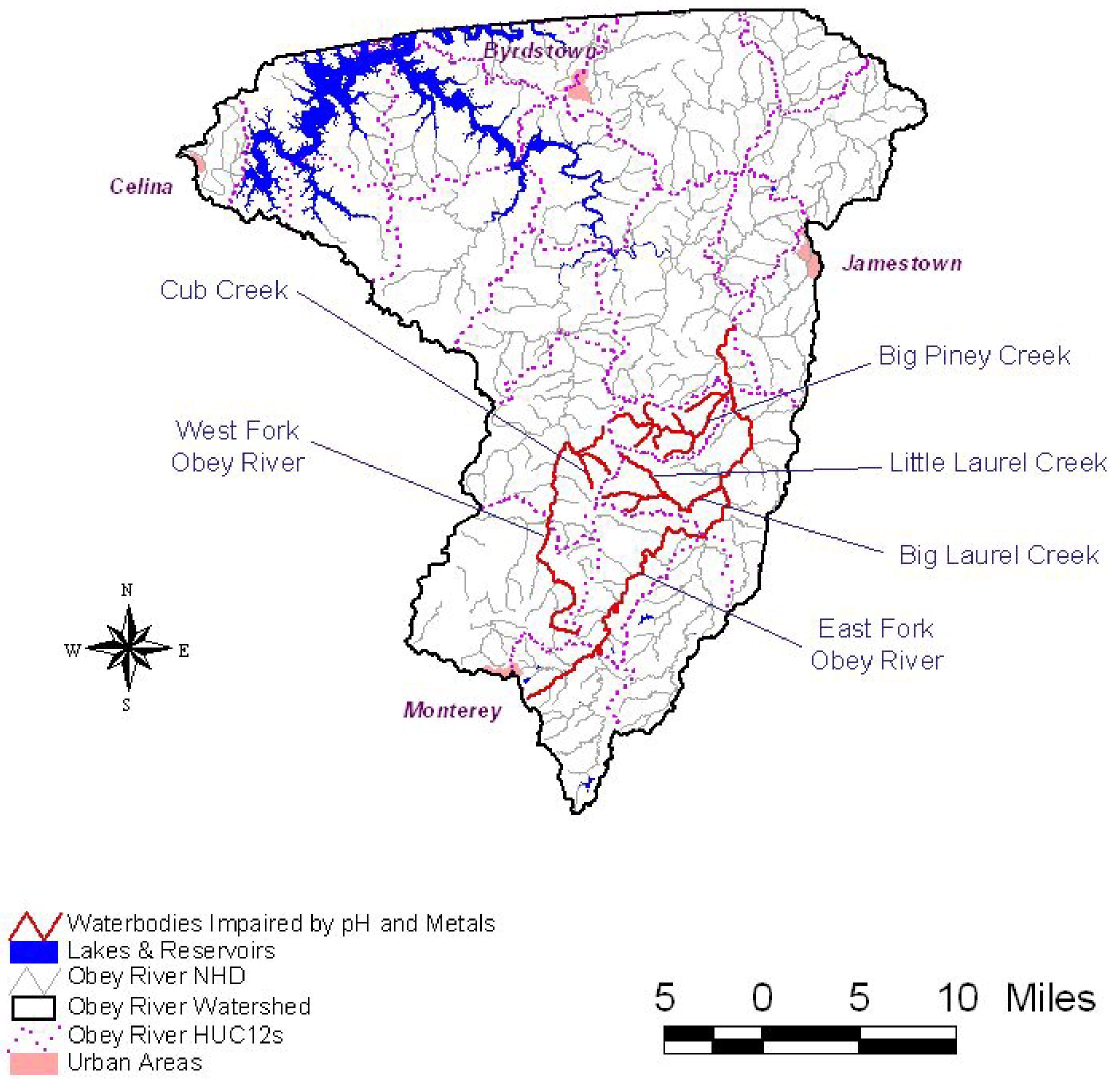

Figure 4 Obey River Watershed pH- and Metal-Impaired Segments

4.0 TARGET IDENTIFICATION

The allowable instream range of pH for the Obey River watershed, is established in *State of Tennessee Water Quality Standards, Chapter 1200-4-3 General Water Quality Criteria, January, 2004 (Revised)* (TDEC, 2004) for applicable use classifications. The Fish & Aquatic Life criteria pH range for "all other wadeable streams" of 6.0 to 9.0 is the most stringent for the waterbodies covered by this TMDL. The criteria were approved by the Environmental Protection Agency (EPA) in September 2004.

According to the Pennsylvania Department of Environmental Protection (PDEP, 1998), the "acidity or net alkalinity of a solution, not the pH, is probably the best single indicator of the severity of AMD." In order to facilitate analysis of existing pollutant loads and load reductions required to restore the Obey River watershed to fully supporting all of its designated use classifications, net alkalinity will be used as a surrogate parameter for TMDL development. For the purposes of this TMDL, the following terms are defined:

Acidity	The quantitative capacity of a water to react with a strong base to a designated pH. Expressed as milligrams per liter calcium carbonate.
Total Alkalinity	A measure of the ability of water to neutralize acids. Expressed as milligrams per liter calcium carbonate.
Net Alkalinity	The total alkalinity minus the acidity. Expressed as milligrams per liter calcium carbonate.

Since there is no specified numerical criterion for net alkalinity, a net alkalinity of 10.8 mg/l $CaCO_3$, was selected as the numerical target for this TMDL based on analysis of all available monitoring data for Tennessee (see Appendix C). In order to characterize net alkalinity (as $CaCO_3$) over the range of flow conditions encountered in the watershed, the target net alkalinity (as $CaCO_3$) is expressed by means of a target load duration curve. The target load duration curve, developed in Appendix E, is shown in Figure 5. In order to meet Tennessee Water Quality Standards for pH, this TMDL requires that net alkalinity (as $CaCO_3$) loads of streams in the Obey River watershed meet, or exceed, the loads per unit area specified in the target load duration curve.

There is currently no numerical criterion for iron established in *State of Tennessee Water Quality Standards, Chapter 1200-4-3 General Water Quality Criteria, January 2004 (Revised)* (TDEC, 2004). U.S.EPA has published National Recommended Water Quality Criteria (USEPA, 2006). The recommended Criterion Continuous Concentration (CCC) for iron for the protection of fish & aquatic life is 1000 μg/L (1.0 mg/L) and has been selected as the appropriate numeric target for waterbodies not designated for drinking water supply in the Obey River watershed. TDEC believes that meeting this criterion will satisfy the requirement that "waters shall not contain substances or a combination of substances including disease-causing agents which, by way of either direct exposure or indirect exposure through food chains, may cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), physical deformations, or restrict of impair growth in fish or aquatic life or their offspring". The water quality criteria of 300 μg/L (0.30 mg/L) established in the *Secondary maximum contaminant levels (40 CFR §143.3)* has been selected as the appropriate numeric target for waterbodies designated for drinking water supply in the Obey River watershed.

There is currently no numerical criterion for aluminum established in *State of Tennessee Water Quality Standards, Chapter 1200-4-3 General Water Quality Criteria, January 2004 (Revised)* (TDEC, 2004). A water quality criteria of 50-200 μg/L (0.05-0.20 mg/L) is established in the *Secondary maximum contaminant levels (40 CFR §143.3).* Therefore, the upper limit of 200 μg/L has been selected as the appropriate numeric target for waterbodies designated for drinking water supply in the Obey River watershed.

There is currently no numerical criterion for manganese established in *State of Tennessee Water Quality Standards, Chapter 1200-4-3 General Water Quality Criteria, January 2004 (Revised)* (TDEC, 2004). The water quality criteria of 50 μg/L (0.05 mg/L) established in the *Secondary maximum contaminant levels (40 CFR §143.3)* has been selected as the appropriate numeric target for waterbodies designated for drinking water supply in the Obey River watershed. For Cub Creek, which is not designated for drinking water supply, there is not a specific numeric target for manganese. According to the "Gold Book" (USEPA, 1986), manganese is not considered to be a problem in fresh waters. TDEC believes that meeting the water quality criteria for pH (and its surrogate net alkalinity) and iron will also ensure that Cub Creek is no longer impaired for manganese.

East Fork Obey River and West Fork Obey River were identified on the Final 2006 303(d) list as impaired due to "metals" rather than specific metals. Based on review of literature (USEPA, 1975; USEPA, 2001), the metals which most frequently exceed acceptable levels in waste water from coal production facilities or abandoned mine sites include: aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, silver, and zinc. Water quality criteria, where available, for each metal and designated use are summarized in Table 3. TDEC believes that meeting the criteria specified in Table 3 will satisfy the requirement that "waters shall not contain toxic substances at concentrations that cause toxicity or in such amounts that interfere with habitat due to precipitation or bacteria growth".

In accordance with the guidance in *Technical Support Document For Water Quality-based Toxics Control* (USEPA, 1991b), fish & aquatic life criteria are interpreted to mean that the 1-hour average exposure should not exceed the Criterion Maximum Concentration (CMC) and the 4-day average exposure should not exceed the Criterion Continuous Concentration (CCC). Excursions of CMCs & CCCs should not exceed a frequency of once every three years.

Table 3 Metals Criteria for Each Designated Use Classification

Metal (Total Recoverable)	Designated Use Classification	Criteria [µg/l]	Source of Criteria
Aluminum	Drinking Water Supply	50 – 200	40 CFR §143.3
Arsenic	Drinking Water Supply	10	40 CFR §141.62; TDEC, 2004
Arsenic	Recreation (Organisms Only)	10	TDEC, 2004
Cadmium	Drinking Water Supply	5	40 CFR §141.62; TDEC, 2004
Cadmium	Fish & Aquatic Life (CCC)	a	TDEC, 2004
Chromium	Drinking Water Supply	100	40 CFR §141.62; TDEC, 2004
Chromium	Fish & Aquatic Life (CCC)	a	TDEC, 2004
Copper	Drinking Water Supply	1000	40 CFR §143.3
Copper	Fish & Aquatic Life (CCC)	a	TDEC, 2004
Iron	Drinking Water Supply	300	40 CFR §143.3
Iron	Fish & Aquatic Life (CCC)	1000	USEPA, 2006
Lead	Drinking Water Supply	5	TDEC, 2004
Lead	Fish & Aquatic Life (CCC)	a	TDEC, 2004
Manganese	Drinking Water Supply	50	40 CFR §143.3
Nickel	Drinking Water Supply	100	40 CFR §141.62; TDEC, 2004
Nickel	Recreation (Organisms Only)	4600	TDEC, 2004
Nickel	Fish & Aquatic Life (CCC)	a	TDEC, 2004
Zinc	Drinking Water Supply	5000	40 CFR §143.3
Zinc	Fish & Aquatic Life (CCC)	a	TDEC, 2004

a Criteria for the protection of fish & aquatic life are a function of water hardness (as $CaCO_3$). Criteria for these metals, as well as the instream total recoverable concentrations (ITRCs) required to comply with these criteria, were calculated in accordance with *State of Tennessee Water Quality Standards* using the methodology described in *The Metals Translator: Guidance For Calculating A Total Recoverable Permit Limit From a Dissolved Criterion*, EPA 823-B-96-007, June 1996 (USEPA 1996).

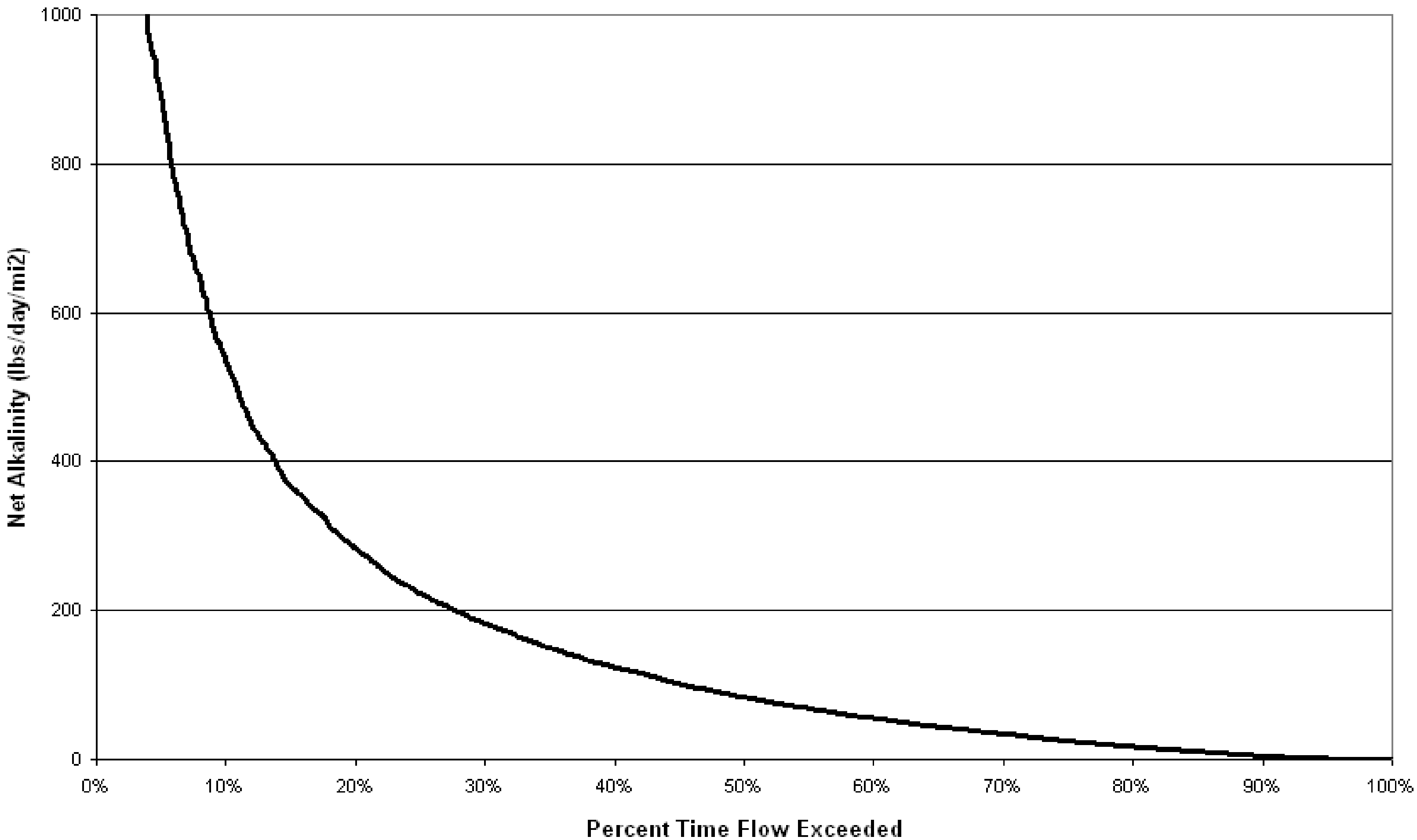

Figure 5 Target Net Alkalinity Load Duration Curve

5.0 WATER QUALITY ASSESSMENT AND DIFFERENCE FROM TARGET

Water quality monitoring of the Obey River Watershed was conducted by Division of Water Pollution Control (DWPC) personnel from the Cookeville Environmental Field Office (EFO) during the period from 7/11/00 through 8/17/04. Two monitoring stations were located on impaired segments of West Fork and East Fork Obey River (see Figure 6).

- EFOBE039.6OV – East Fork Obey River, at Cliff Springs Rd.
- WFOBE009.5OV – West Fork Obey River, at Shiloh Rd. bridge

East Fork Obey River and West Fork Obey River were identified on the Final 2006 303(d) list as impaired due to “metals” rather than specific metals. Based on review of literature (USEPA, 1975; USEPA, 2001), the metals which most frequently exceed acceptable levels in waste water from coal production facilities or abandoned mine sites include: aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, silver, and zinc. The pH and metal data collected at each monitoring site (ref: Appendix B) in the Obey River watershed are tabulated and compared to the appropriate targets in Table 4. No monitoring data was available for silver.

Analysis of monitoring data for West Fork Obey River suggests that it is no longer impaired for pH, iron, manganese, arsenic, cadmium, chromium, copper, lead, nickel, and zinc. At this time, de-listing is suggested for pH and “metals”. Analysis of monitoring data for East Fork Obey River suggests that it is still impaired for pH, aluminum, iron, and manganese. At this time, de-listing is suggested for “metals” and listing is suggested for aluminum, iron, and manganese.

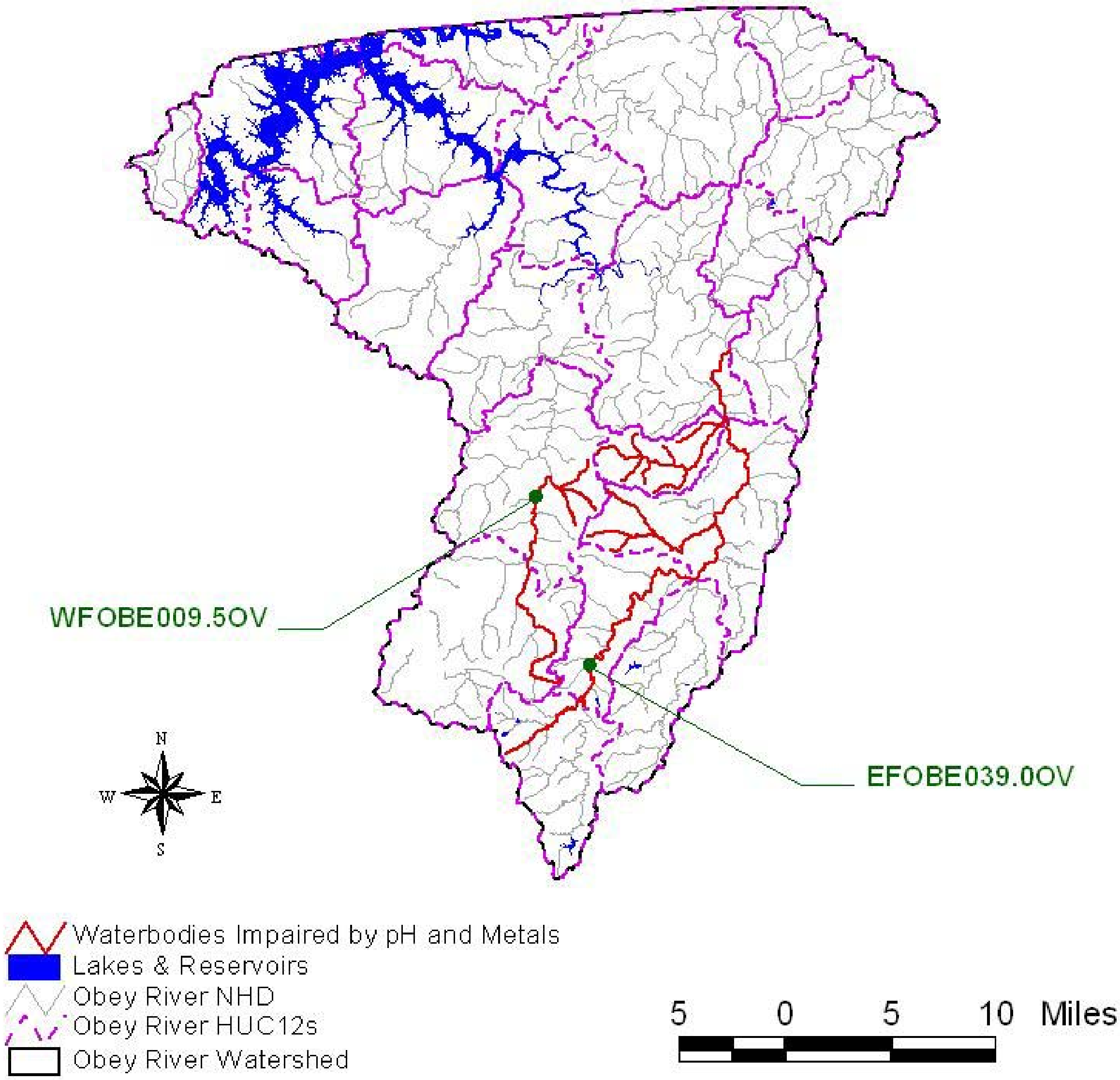

Figure 6 Obey River Watershed Monitoring Stations

Table 4 Summary of TDEC Water Quality Monitoring Data

Monitoring Station	Date Range	Parameter	Data Pts.	Target (μg/L)	Min. (μg/L)	Avg. (μg/L)	Max. (μg/L)	No. Exceed. Target
EFOBE039.0OV	2000 – 2004	pH [a]	19	6.0-9.0	3.1	4.3	7.8	8
		Aluminum	10	200	100U	334.3	471	7
		Arsenic	18	10 [b]	1U	0.50	1.0	0
		Iron	18	300 [b]	32	298.4	955	8
		Manganese	19	50 [b]	59	421.7	1750	19
		Cadmium	19	[c]	1U	0.58	2.0	0 [d]
		Chromium	19	[c]	1U	0.61	2.0	0
		Copper	19	[c]	1U	1.8	4.0	0
		Lead	19	[c]	1U	0.61	2.0	0
		Nickel	19	[c]	10U	10U	10U	0
		Zinc	19	[c]	1U	8.2	16.0	0
WFOBE009.5OV	2003 – 2004	pH [a]	8	6.0-9.0	7.5	7.85	8.2	0
		Arsenic	8	10	1U	0.56	1.0	0
		Iron	8	1000	73	105.4	164	0
		Cadmium	8	[c]	1U	1U	1U	0
		Chromium	8	[c]	1U	1U	1U	0
		Copper	8	[c]	1U	1.6	4.0	0
		Lead	8	[c]	1U	1U	1U	0
		Nickel	8	[c]	10U	10U	10U	0
		Zinc	8	[c]	1U	1.3	2.0	0

[a] pH is expressed in standard units (s.u.)
[b] Target for East Fork Obey River is based on designation as domestic water supply.
[c] Target for these metals is a function of water hardness.
[d] The observed value for cadmium was only greater than the target concentration when the target concentration was less than half of the method detention limit. These occurrences are considered to be exceptions, rather than exceedances, because the exceedance cannot be proven.

6.0 SOURCE ASSESSMENT

An important part of the TMDL analysis is the identification of individual sources, or source categories, of low pH and high metals in the watershed and the amount of pollutant loading contributed by each of these sources. Sources are broadly classified as either point or non-point sources. A point source can be defined as a discernable, confined, and discrete conveyance from which pollutants are or may be discharged to surface waters. Non-point sources include all other sources of pollution.

6.1 Point Sources

There are 11 facilities in the Obey River Watershed that have NPDES permits authorizing the discharge of wastewater due to mine operations. Four of these facilities are coal mining operations and are located in impaired subwatersheds (see Table 5 & Figure 7). The permit limits for discharges from these facilities are in accordance with the effluent limitations specified in 40 CFR §434.35 and are given in Table 6. There is no limit for aluminum in the permit because aluminum is believed to be absent from discharges from mine operations. Two of these mines (Cumberland Mine #1 & #2) have been reclaimed and are not longer required to monitor for metals.

Table 5 NPDES Permitted Coal Mines in Impaired Subwatersheds

NPDES Permit No.	Facility	Size (acres)	Receiving Stream
TN0053007	LCC of Tennessee, LLC Grimsley Tipple Mine	27.27	Fern Camp Creek
TN0071188	LCC of Tennessee, LLC Cumberland Mine #1	195.4	Lints Cove
TN0071498	LCC of Tennessee, LLC Cumberland Mine #2	629	Fern Camp Creek & Lints Cove
TN0071897	Hood Coal Corporation Tar Gap Mine	640.7	Unnamed Tributaries to Gwinn Cove & East Fork Obey River

Table 6 NPDES Permit Limits

Constituent	Monthly Average	Daily Max
Iron, total	3.0 mg/L	6.0 mg/L
Manganese, total	2.0 mg/L	4.0 mg/L
Total Suspended Solids	35.0 mg/L	70.0 mg/L
Settleable Solids	NA	0.5 mg/L
pH	6.5 to 9.0 Standard Units at all times	

6.2 Non-point Sources

There are a number of abandoned surface mining sites in the Obey River watershed that are susceptible to the formation of acid mine drainage as discussed in Appendix A. In the 2006 303(d) List (ref.: Table 2), abandoned mining was identified as the source of low pH and high metals in several impaired waterbodies in the watershed.

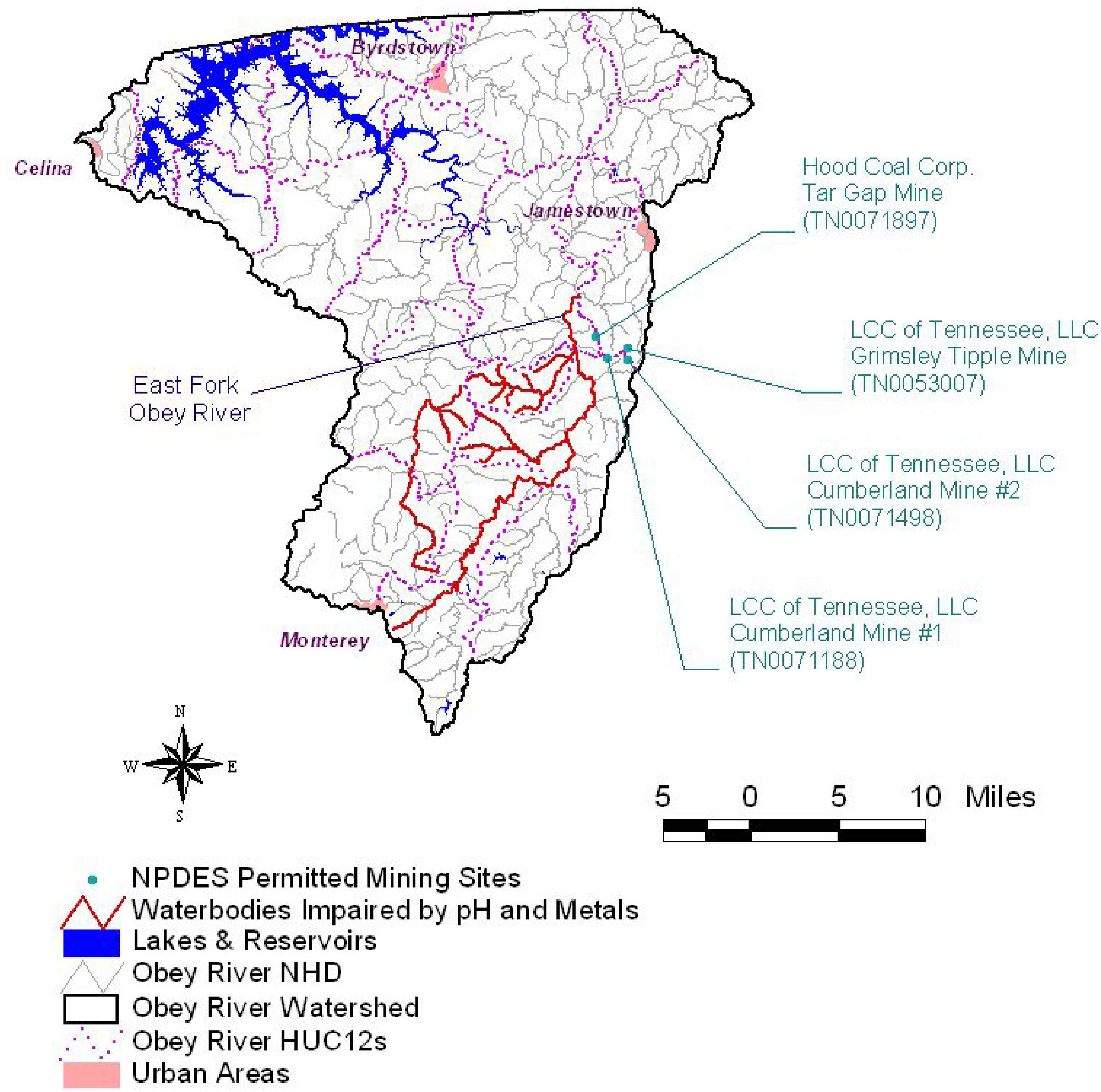

Figure 7 NPDES Permitted Mines in the Obey River Watershed

7.0 DEVELOPMENT OF TOTAL MAXIMUM DAILY LOAD

The TMDL process quantifies the amount of a pollutant that can be assimilated in a waterbody, identifies the sources of the pollutant, and recommends regulatory or other actions to be taken to achieve compliance with applicable water quality standards based on the relationship between pollution sources and in-stream water quality conditions. A TMDL can be expressed as the sum of all point source loads (Waste Load Allocations), non-point source loads (Load Allocations), and an appropriate margin of safety (MOS) which takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$TMDL = \Sigma\ WLAs + \Sigma\ LAs + MOS$$

The objective of a TMDL is to allocate loads among all of the known pollutant sources throughout a watershed so that appropriate control measures can be implemented and water quality standards achieved. 40 CFR §130.2 (i) states that TMDLs can be expressed in terms of mass per time (e.g. pounds per day), toxicity, or other appropriate measure.

7.1 Expression of TMDLs, WLAs, & LAs

In this document, the TMDL for each constituent is a daily load expressed as a function of mean daily flow (daily loading function). WLAs & LAs are also expressed as daily loading functions in lbs/day/acre. For implementation purposes, corresponding percent load reduction goals (PLRGs) to decrease constituent loads to TMDL target levels are also expressed.

7.2 TMDL Analysis Methodology

TMDLs for the Obey River watershed were developed using load duration curves for analysis of impaired waterbodies. A load duration curve (LDC) is a cumulative frequency graph that illustrates existing water quality conditions (as represented by loads calculated from monitoring data), how these conditions compare to desired targets, and the portion of the waterbody flow zone represented by these existing loads. Load duration curves are considered to be well suited for analysis of periodic monitoring data collected by grab sample. LDCs were developed at monitoring site locations in impaired waterbodies and daily loading functions were expressed for TMDLs, WLAs, LAs, and MOS.

7.3 TMDL Representation

In general, waterbodies become impaired due to excessive loading of particular pollutants that result in concentrations that violate instream water quality standards. A TMDL establishes the maximum load that can be assimilated by the waterbody, without violating standards, and allocates portions of this load to point and non-point sources. This normally involves reductions in loading from existing levels, with WLAs & LAs of zero load reduction as the ideal.

The use of net alkalinity as a surrogate parameter, however, requires a different approach. Existing levels of net alkalinity in impaired subwatersheds may be negative, while target values are positive. The concept of a “maximum net alkalinity load” does not appropriately represent the desired target condition with respect to AMD caused impairment. Net alkalinity targets can be achieved by reducing acidity, increasing total alkalinity, or some combination of both.

7.4 Critical Conditions and Seasonal Variation

The critical condition for non-point source metals loading is an extended dry period followed by a rainfall runoff event. During the dry weather, metals build up on the land surface and are washed off by rainfall. The critical condition for point source loading occurs during period of low streamflow when dilution is minimized. Both conditions are represented in the TMDL analyses.

The ten-year period from January 1, 1996 to December 31, 2005 was used to simulate flow. This 10-year period contained a range of hydrologic conditions that included both low and high streamflows. Critical conditions and seasonal variation are accounted for in the load duration curve analyses by using the entire period of flow and water quality data available for the impaired waterbodies. In the East Fork and West Fork Obey River subwatersheds, water quality data have been collected during most flow ranges.

7.5 Margin of Safety

There are two methods for incorporating an MOS in the analysis: a) implicitly incorporate the MOS using conservative model assumptions to develop allocations; or b) explicitly specify a portion of the TMDL as the MOS and use the remainder for allocations.

For development of net alkalinity TMDLs, an implicit MOS was incorporated through the use of conservative modeling assumptions. These include: 1) the use of a 10-year continuous simulation that incorporates a wide range of meteorological events, 2) the use of the load duration curve, which addresses pollutant loading over the entire range of flow, and 3) the use of a positive net alkalinity target of 10.8 mg/L based on analysis of all available monitoring data for Tennessee (see Appendix C).

For development of aluminum, iron, and manganese TMDLs, an explicit MOS, equal to 10% of the water quality targets (ref.: Section 4.0), was utilized for determination of WLAs and LAs:

Instantaneous Maximum for Iron (East Fork Obey only)	MOS = 30 μg/L
Instantaneous Maximum for Iron (all other waterbodies)	MOS = 100 μg/L
Instantaneous Maximum for Manganese (East Fork Obey only)	MOS = 5 μg/L
Instantaneous Maximum for Aluminum (East Fork Obey only)	MOS = 20 μg/L

7.6 Determination of Total Maximum Daily Loads

Daily loading functions were calculated for impaired segments in the Obey River watershed using LDCs to evaluate compliance with the maximum target concentrations according to the procedure in Appendix E. These TMDL loading functions for impaired segments and subsequent subwatersheds are shown in Table 7. Note that for net alkalinity, the TMDL represents the minimum loading rather than the maximum loading.

7.7 Determination of WLAs, & LAs

WLAs and LAs were determined according to the procedures in Appendix E. These allocations represent the available loading <u>after application of the explicit MOS</u>. For waterbodies with no active mining operations, there is no WLA and the LA for pH is equal to the TMDL for pH. For waterbodies with no active mining operations, there is no WLA and the LA for each metal is equal to the TMDL – MOS. The TMDLs, WLAs, and LAs for net alkalinity, aluminum, iron, and manganese in the Obey River watershed are summarized in Table 7.

Table 7. TMDLs, WLAs, & LAs expressed as daily loads for Impaired Waterbodies in the Obey River Watershed (HUC05130105)

Impaired Waterbody Name	Impaired Waterbody ID	Constituent	PLRG [%]	TMDL [lbs/day]	Explicit MOS [lbs/day]	WLAs [lbs/day/ac]	LAs [lbs/day/ac]
Cub Creek	TN05130105015 – 0300	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	$1.56 \times 10^{-2} \times Q$
		Iron	NA	5.38 x Q	0.538 x Q	NA	$1.30 \times 10^{-3} \times Q$
West Fork Obey River	TN05130105015 – 2000	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	$1.33 \times 10^{-3} \times Q$
		Iron	NR	5.38 x Q	0.538 x Q	NA	$1.10 \times 10^{-4} \times Q$
Big Laurel Creek	TN05130105019 – 1100	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	$7.20 \times 10^{-3} \times Q$
		Iron	NA	5.38 x Q	0.538 x Q	NA	$6.00 \times 10^{-4} \times Q$
Little Laurel Creek	TN05130105019 – 1110	Net Alkalinity	NA	58.1 x Q	NA[b]	NA	$2.39 \times 10^{-2} \times Q$
		Iron	NA	5.38 x Q	0.538 x Q	NA	$1.99 \times 10^{-3} \times Q$
Big Piney Creek	TN05130105019 – 1200	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	$6.11 \times 10^{-3} \times Q$
East Fork Obey River	TN05130105019 – 2000	Net Alkalinity	NA	58.1 x Q	NA[a]	$58.1 \times Q_2$	$(5.36 \times 10^{-4} \times Q) – (5.36 \times 10^{-4} \times Q_2)$
		Iron	42.3	1.61 x Q	0.161 x Q	$16.1 \times Q_2$	$(1.34 \times 10^{-5} \times Q) – (1.49 \times 10^{-4} \times Q_2)$
		Manganese	95.9	0.269 x Q	$2.69 \times 10^{-2} \times Q$	$10.8 \times Q_2$	$(2.23 \times 10^{-6} \times Q) – (9.93 \times 10^{-5} \times Q_2)$
		Aluminum	57.3	1.076 x Q	0.1076 x Q	NA	$4.46 \times 10^{-5} \times Q$
East Fork Obey River	TN05130105019 – 3000	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	$2.68 \times 10^{-3} \times Q$
		Iron	42.3	1.61 x Q	0.161 x Q	NA	$6.69 \times 10^{-5} \times Q$
		Manganese	95.9	0.269 x Q	$2.69 \times 10^{-2} \times Q$	NA	$1.12 \times 10^{-5} \times Q$
		Aluminum	57.3	1.076 x Q	0.1076 x Q	NA	$4.46 \times 10^{-5} \times Q$

Notes: NA = Not Applicable.
NR = No Reduction Required
PLRG = Percent Load Reduction Goal
Q = Mean Daily In-stream Flow (cfs).
Q_2 = Mean Daily Flow (cfs) from Permitted Point Sources (combined)

a. For development of net alkalinity TMDLs, an implicit MOS was incorporated through the use of conservative modeling assumptions (see Section 7.5).

8.0 IMPLEMENTATION PLAN

Monitoring conducted in 2000 thru 2004 has identified a number of waterbodies in the Obey River watershed as impaired due to low pH and/or high metals. This condition is a result of AMD from land disturbance caused by current and past coal mining activities. It should be noted that the stream water quality documented during sampling conducted for this TMDL is not typical of the more severe acid mine drainage situations. Acid mine drainage has one or more of four major components: high acidity (low pH < 6 or alkalinity < 20 mg/L), high metal concentrations (> 500 μg/L), elevated sulfate levels (> 74 mg/L), and excessive suspended solids and/or siltation. While monitoring data for East Fork Obey River indicates high acidity, low pH, and high metals, monitoring data for West Fork Obey River suggests that it is no longer impaired for metals. At this time, de-listing of West Fork Obey River for pH and metals is suggested. At this time, de-listing of East Fork Obey River is suggested for "metals" and listing of East Fork Obey River is suggested for aluminum, iron, and manganese.

Individual metal load reduction goals were calculated for impaired segments using Load Duration Curves to evaluate compliance with the target concentrations according to the procedure in Appendix E. The load reductions were calculated at each monitoring site within the drainage area for which monitoring data was available. (No monitoring data was available for Cub Creek, Big Laurel Creek, Little Laurel Creek, and Big Piney Creek.) The load reductions for the Obey River Watershed are also summarized in Table 7.

Required LAs will be implemented in several steps to reduce acidity and/or increase total alkalinity so as to result in an increase of instream net alkalinity. In order to meet Tennessee Water Quality Standards for pH, this TMDL requires that net alkalinity (as $CaCO_3$) loads of streams in the Obey River watershed meet, or exceed, the daily loading functions specified in Table 7.

Step 1: Conduct water quality testing for Cub Creek, Big Piney Creek, and Big and Little Laurel Creek to confirm the status of each waterbody as impaired by pH and/or metals. No monitoring data was available for these waterbodies.

Step 2: Conduct additional water and minespoil testing to identify specific AMD sites and delineate actual areas of acid production at each site. The headwaters of East Fork Obey River are of special interest. The monitoring site used to evaluate to the impaired segments is upstream of all permitted mining sources, suggesting other potential sources of impairment.

Step 3: Once sites have been identified, remediation plans will be developed utilizing primarily passive treatment schemes (versus treatment by chemical addition) to provide a long-term solution to stream impairment. Remediation measures that have proved successful include, but are not limited to:

- Regrading of spoil
- Isolation of acid producing material from water contact
- Anoxic limestone drains
- Constructed wetlands.

The Abandoned Mine Lands Section of the DWPC has expertise in the development of AMD remediation plans and has completed a number of reclamation projects on abandoned mines in the Tennessee coalfield. A number of these projects have included measures designed to remediate acid production caused by land disturbance due to past mining. One reclamation project was completed at the Three Sisters site in the North Chickamauga Creek subwatershed in 2000 at a cost of $95,000.

The Mining Section issues NPDES permits for discharges of wastewater from coal and non-coal mines and, where applicable, Mining Law permits to non-coal facilities in Tennessee. This section of the DWPC has worked with a number of permitted mine sites, offering considerable technical advice in the remediation of problems similar to those found in the Obey River watershed.

Step 4: Conduct follow-on water quality testing of impaired waterbodies in the East Fork and West Fork Obey River watersheds to verify the effectiveness of remediation measures. Parameters should include flow, pH, acidity, total alkalinity, and metals (aluminum, iron, and manganese, as appropriate).

9.0 PUBLIC PARTICIPATION

In accordance with 40 CFR §130.7, the proposed pH TMDL for the Obey River Watershed was placed on Public Notice for a 35-day period and comments solicited. Steps that were taken in this regard include:

1) Notice of the proposed TMDL was posted on the Tennessee Department of Environment and Conservation website. The announcement invited public and stakeholder comment and provided a link to a downloadable version of the TMDL document.

2) Notice of the availability of the proposed TMDL (similar to the website announcement) was included in one of the NPDES permit Public Notice mailings which is sent to approximately 90 interested persons or groups who have requested this information.

3) Letters were sent to NPDES-permitted mines located in pH- or metal-impaired subwatersheds or drainage areas in the Obey River Watershed, advising them of the proposed TMDLs and their availability on the TDEC website. The letters also stated that a copy of the draft TMDL document would be provided on request. A letter was sent to the following entities:

   LCC of Tennessee, LLC, Grimsley Tipple Mine (TN0053007)
   LCC of Tennessee, LLC, Cumberland Mine #1 (TN0071188)
   LCC of Tennessee, LLC, Cumberland Mine #2 (TN0071498)
   Hood Coal Corp., Tar Gap Mine (TN0071897)

No comments were received during the public notice period.

10.0 FURTHER INFORMATION

Further information concerning Tennessee's TMDL program can be found on the Internet at the Tennessee Department of Environment and Conservation website:

www.state.tn.us/environment/wpc/tmdl.htm

Technical questions regarding this TMDL should be directed to the following members of the Division of Water Pollution Control staff:

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REFERENCES

Electronic Code of Federal Regulations (e-CFR). “New Source Performance Standards (NSPS)“, 40 CFR §434.35. current as of May 5, 2006.

Electronic Code of Federal Regulations (e-CFR). “Secondary Maximum Contaminant Levles“, 40 CFR §143.3. current as of May 5, 2006.

Lumb, A.M., McCammon, R.B., and Kittle, J.L., Jr., 1994. Users Manual for an expert system, (HSPFEXP) for calibration of the Hydrologic Simulation Program –Fortran: U.S. Geological Survey Water-Resources Investigation Report 94-4168,102 p.

PDEP. 1998. *Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania*. Pennsylvania Department of Environmental Protection, Harrisburg, Pennsylvania. 5600-BK-DEP2256, August 1998.

Stiles, T., and B. Cleland, 2003. Using Duration Curves in TMDL Development and Implementation Planning. ASIWPCA “States Helping States” Conference Call, July 1, 2003. This document is available on the Indiana Office of Water Quality website: http://www.in.gov/idem/water/planbr/wqs/tmdl/durationcurveshscall.pdf .

TDEC. 2004. *State of Tennessee Water Quality Standards, Chapter 1200-4-3 General Water Quality Criteria, January 2004 (Revised).* State of Tennessee, Department of Environment and Conservation, Division of Water Pollution Control.

TDEC. 2006. *Final 2006 303(d) List.* State of Tennessee, Department of Environment and Conservation, Division of Water Pollution Control, October 2006.

USEPA. 1975. *Development Document For Interim Final Effluent Limitations Guidelines for the Coal Mining Point Source Category.* U.S. Environmental Protection Agency, Washington, DC. Publication Number 440175057, October 1975.

USEPA. 1986. *Quality Criteria for Water.* U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA-440/5-86-001, 1986.

USEPA. 1991a. *Guidance for Water Quality –based Decisions: The TMDL Process.* U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA-440/4-91-001, April 1991.

USEPA. 1991b. *Technical Support Document For Water Quality –based Toxics Control.* U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA-505/2-90-001.

USEPA. 1996. *The Metals Translator: Guidance for Calculating a Total Recoverable Permit Limit from a Dissolved Criterion.* U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA-823/B-96-007.

USEPA. 1997. *Ecoregions of Tennessee*. U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, Oregon. EPA/600/R-97/022.

USEPA. 2001. *Abandoned Mine Site Characterization and Cleanup Handbook.* U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC. EPA-530-R-01-002, March 2001.

USEPA. 2006. *National Recommended Water Quality Criteria.* U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology (4304T), Washington, DC. 2006.

APPENDIX A

Acid Mine Drainage

Acid Mine Drainage Formation

The following information regarding acid mine drainage formation was taken from the U.S. Department of Interior, Office of Surface Mining (OSM) website at www.osmre.gov/amdform.htm. The first section on the Chemistry of Pyrite Weathering is reproduced below. Discussion of subsequent sections can be found on the OSM website.

The formation of acid drainage is a complex geochemical and microbially mediated process. The acid load ultimately generated from a minesite is primarily a function of the following factors:

- Chemistry
- Microbiological Controls
- Depositional environment
- Acid/base balance of the overburden
- Lithology
- Mineralogy
- Minesite hydrologic conditions

Chemistry of Pyrite Weathering

A complex series of chemical weathering reactions are spontaneously initiated when surface mining activities expose spoil materials to an oxidizing environment. The mineral assemblages contained in the spoil are not in equilibrium with the oxidizing environment and almost immediately begin weathering and mineral transformations. The reactions are analogous to “geologic weathering” which takes place over extended periods of time (i.e., hundreds to thousands of years) but the rates of reaction are orders of magnitude greater than in “natural” weathering systems. The accelerated reaction rates can release damaging quantities of acidity, metals, and other soluble components into the environment. The pyrite oxidation process has been extensively studied and has been reviewed by Nordstrom (1979). For purposes of this description, the term “pyrite” is used to collectively refer to all iron disulfide minerals.

The following equations show the generally accepted sequence of pyrite reactions:

$2\ FeS_2 + 7\ 0_2 + 2\ H_2O \rightarrow\rightarrow 2\ Fe^{2+} + 4\ SO_4^{2-} + 4\ H^+$ (Equation 1)

$4\ Fe^{2+} + O_2 + 4\ H^+ \rightarrow 4\ Fe^{3+} + 2\ H_2O$ (Equation 2)

$4\ Fe^{3+} + 12\ H_2O \rightarrow 4\ Fe(OH)_3 + 12\ H^+$ (Equation 3)

$FeS_2 + 14\ Fe^{3+} + 8\ H_2O \rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+$ (Equation 4)

In the initial step, pyrite reacts with oxygen and water to produce ferrous iron, sulfate and acidity. The second step involves the conversion of ferrous iron to ferric iron. This second reaction has been termed the “rate determining” step for the overall sequence.

The third step involves the hydrolysis of ferric iron with water to form the solid ferric hydroxide (ferrihydrite) and the release of additional acidity. This third reaction is pH dependent. Under very acid conditions of less than about pH 3.5, the solid mineral does not form and ferric iron remains in solution. At higher pH values, a precipitate forms, commonly referred to as "yellowboy."

The fourth step involves the oxidation of additional pyrite by ferric iron. The ferric iron is generated by the initial oxidation reactions in steps one and two. This cyclic propagation of acid generation by iron takes place very rapidly and continues until the supply of ferric iron or pyrite is exhausted. Oxygen is not required for the fourth reaction to occur.

The overall pyrite reaction series is among the most acid-producing of all weathering processes in nature.

APPENDIX B

Obey River Watershed Monitoring Data

Table B-1 West Fork Obey River Monitoring Data

	West Fork Obey River					36 11' 03"N		
	Mile 9.5					85 09' 53"W		
Test	*Units*	*12/10/03*	*1/13/04*	*2/17/04*	*3/17/04*	*4/19/04*	*5/18/04*	*6/23/04*	*8/17/04*
pH	--	7.60	7.50	8.10	8.20	8.20	8.02	7.80	8.02
Conductivity	uMHO	212.0	205.0	198.0	210.3	191.2	250.0	265.8	300.6
Dissolved Oxygen	mg/L	9.8	11.0	10.6	12.1	12.2	10.0	9.5	9.4
Flow	cfs								
Temperature	Celsius	11.9	8.0	9.1	10.7	12.5	16.2	18.0	17.8
Acidity	mg/L								
Total Alkalinity	mg/L								
Sulfate	mg/L	12.4	11.8		12.1	14.4	2U	19.2	22.2
Total Hardness	mg/L	115	141	139	129	132	121	199	104
TSS	mg/L	10U	10U	10U	10U	10U	10U	10U	10U
Turbidity	NTU								
Aluminum	ug/L								
Arsenic	ug/L	1U	1	1U	1U	1U	1U	1U	1U
Cadmium	ug/L	1U	1U	1U	1U	1U	1U	1U	1U
Chromium	ug/L	1U	1U	1U	1U	1U	1U	1U	1U
Copper	ug/L	1U	1	1U	1U	2	1U	4	4
Iron	ug/L	111	84	79	118	109	73	164	105
Lead	ug/L	1U	1U	1U	1U	1U	1U	1U	1U
Manganese	ug/L	6	5	7.00	6	5	10	10	12
Mercury	ug/L	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U
Nickel	ug/L	10U	10U	10U	10U	10U	10U	10U	10U
Silver	ug/L								
Zinc	ug/L	2	1	1U	2	2	1	1U	1

Table B-2 East Fork Obey River Monitoring Data

	East Fork Obey River					**36 18' 03"N**					
	Mile 39.0					**85 11' 41"W**					
Test	*Units*	*7/11/00*	*8/15/00*	*9/20/00*	*10/17/00*	*11/15/00*	*12/12/00*	*1/23/01*	*2/21/01*	*3/21/01*	*5/17/01*
pH	--	6.52	6.08	5.21	3.06	4.60	4.43	5.64	5.01	5.61	7.66
Conductivity	uMHO	149.0	185.0	210.9	166.9	190.4	57.2	38.1	86.2	85.5	84.2
Dissolved Oxygen	mg/L	5.78	10.50	8.09	7.05	8.51	11.51	14.40	11.93	12.00	8.89
Flow	cfs	1.34	2.67	3.33	0.96	3.01	2.96		78.10		
Temperature	Celsius	25.0	21.0	17.8	13.3	4.6	3.6	2.2	7.6	6.5	18.6
Acidity	mg/L										
Total Alkalinity	mg/L										
Sulfate	mg/L	23.3V	53.00	99.00	165.00	95.00	81.50	16.90	15.80	15.20	35.90
Total Hardness	mg/L		115.0	132.0	94.2	74.1	81.0	29.0	28.0	42.0	78.0
TSS	mg/L	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U
Turbidity	NTU										
Aluminum	ug/L		100U	471	462	405	468	410	392	431	115
Arsenic	ug/L	1U	1U	1	1U	1U	1U	1U	1U	1U	1U
Cadmium	ug/L	1U	1U	1U	1U	1U	1U	1U	2.0	1U	1U
Chromium	ug/L	1U	1U	1U	1U	1U	1U	1U	2.0	1U	1U
Copper	ug/L	1U	3	1	2	3	2	2	4	1U	1
Iron	ug/L		32	50	45	56	90	484	396	955	87
Lead	ug/L	1U	1	1U	1U	1U	1U	1U	1U	1U	1U
Manganese	ug/L	82	760	1730	1750	1090	960	133	131	116	199
Mercury	ug/L				0.2U						
Nickel	ug/L	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U
Silver	ug/L										
Zinc	ug/L	2	13	12	14	13	16	14	4	7	9

Test	*Units*	*6/20/01*	*12/10/03*	*1/13/04*	*2/17/04*	*3/17/04*	*4/19/04*	*5/18/04*	*6/23/04*	*8/17/04*
pH	--	7.81	5.91	5.70	6.22	6.28	6.64	6.70	6.76	6.40
Conductivity	uMHO	155.8	76.4	62.8	58.2	66.4	56.2	80.0	94.1	158.0
Dissolved Oxygen	mg/L	6.20	10.70	12.60	11.70	12.20	9.32	9.40	8.47	6.90
Flow	cfs									
Temperature	Celsius	23.5	7.9	3.0	4.1	8.5	13.8	17.6	21.9	18.3
Acidity	mg/L									
Total Alkalinity	mg/L									
Sulfate	mg/L	61.40	22.30	16.00	11.50	12.40	16.80	22.67	23.70	55.70
Total Hardness	mg/L	72.0	46.2	24.2	19.4	23.7	23.1	19.6	23.4	32.6
TSS	mg/L	10.0	10U	10U	10U	10U	10U	10U	10U	10U
Turbidity	NTU									
Aluminum	ug/L	139								
Arsenic	ug/L	1U	1U	1U	1U	1U	1U	1U	1U	1U
Cadmium	ug/L	1U	1U	1U	1U	1U	1U	1U	1U	1U
Chromium	ug/L	1U	1U	1U	1U	1U	1U	1U	1U	1U
Copper	ug/L	2	1U	1U	1U	1U	3	1U	4	3
Iron	ug/L	158	605	284	370	426	297	423	461	152
Lead	ug/L	1U	1U	1U	1U	1U	1U	2	1U	1U
Manganese	ug/L	218	181	108	113	78	70	168	67	59
Mercury	ug/L			0.2U	0.2U	0.2U	0.2U	0.2U	0.2U	0.2U
Nickel	ug/L	10U	10U	10U	10U	10U	10U	10U	10U	10U
Silver	ug/L									
Zinc	ug/L	4	9	4	4	6	8	11	6	1U

APPENDIX C

Development of Target Net Alkalinity

Since there is no numerical criterion for net alkalinity, all available monitoring data for the State of Tennessee was examined in an effort to develop a target net alkalinity.

Of the available monitoring data for waterbodies that are not impaired for pH, 47 data points existed for which numerical values for both acidity and total alkalinity were available. (See Figure C-1.) The highest calculated net alkalinity that fell outside of the desired pH range of 6.0 to 9.0 was 10.78 mg/L as $CaCO_3$ at a pH of 9.1. Therefore, a net alkalinity of 10.8 was selected as the target net alkalinity.

Analysis was then expanded to include monitoring data for waterbodies that are not impaired for pH and for which both total alkalinity and acidity were analyzed, but for which either acidity or total alkalinity, but not both, was not detected. (See Figure C-2.) For the purpose of calculating net alkalinity, the analyte concentrations were estimated to be one half of the appropriate detection limit (10 mg/L for total alkalinity and 1 mg/L for acidity). Of the 211 data points, only 3 points (or 1.4%) exceeded the target net alkalinity value of 10.8 mg/L $CaCO_3$ but were not within the required pH range.

Available monitoring data for waterbodies that are included on the 303(d) List as impaired for pH were also compared to the target net alkalinity. Of 41 data points for which numerical values for both acidity and total alkalinity were available, only 2 points (or 4.9%) exceeded the target net alkalinity value of 10.8 mg/L $CaCO_3$ but was not within the required pH range. These data points were for North Suck Creek on 5/21/2005 (pH 5.14, net alkalinity 16.9) and South Suck Creek on 9/9/2004 (pH 5.2, net alkalinity 29.96). When analysis was expanded to include data points for which both acidity and total alkalinity were analyzed, but for which either acidity or total alkalinity, but not both, was not detected, only 3 points (or 2.0%) exceeded the target net alkalinity value of 10.8 mg/L $CaCO_3$ but were not within the required pH range. These data points were the previously mentioned points for North and South Suck Creek and a data point for North Suck Creek on 3/22/2005 (pH 5.8, net alkalinity 18.5).

Therefore, based on analysis of all available monitoring data for the State of Tennessee, selection of a target net alkalinity of 10.8 mg/L as $CaCO_3$ should provide a pH within the criteria of 6.0 to 9.0 standard pH units for waterbodies with a designated use of Fish & Aquatic Life.

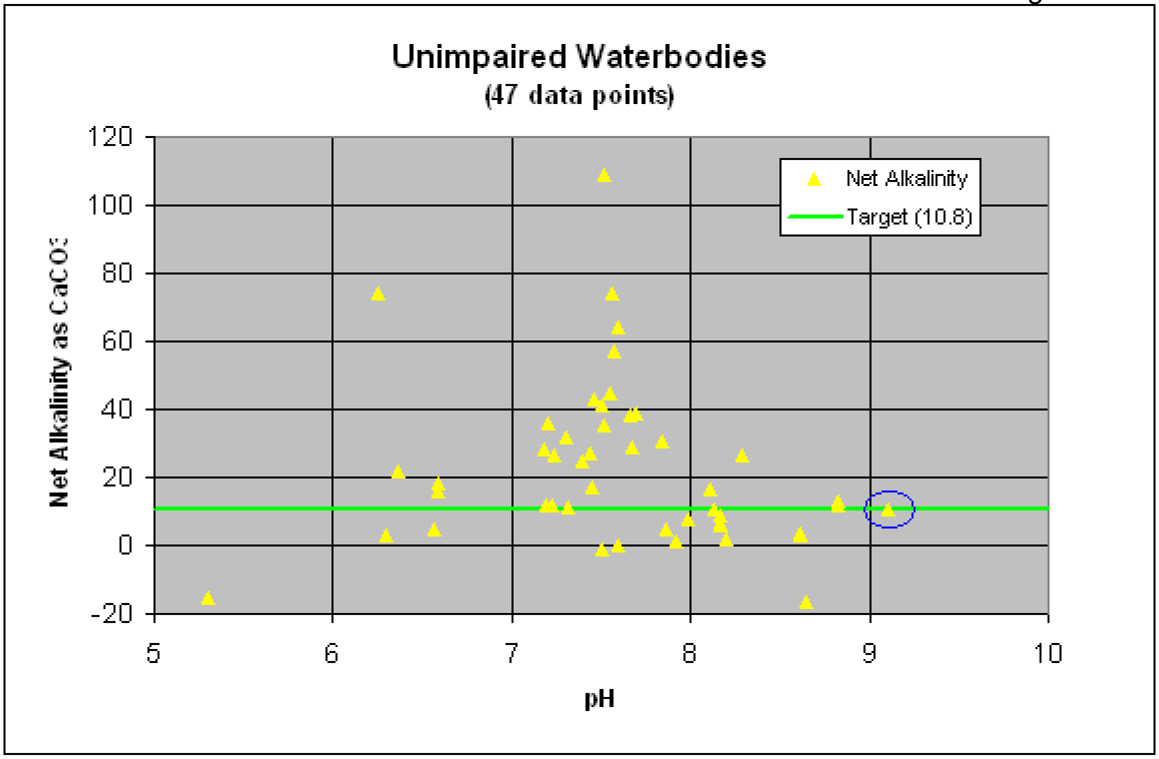

Figure C-1 pH and Net Alkalinity for Unimpaired Waterbodies in Tennessee
(no non-detects for either acidity or total alkalinity)

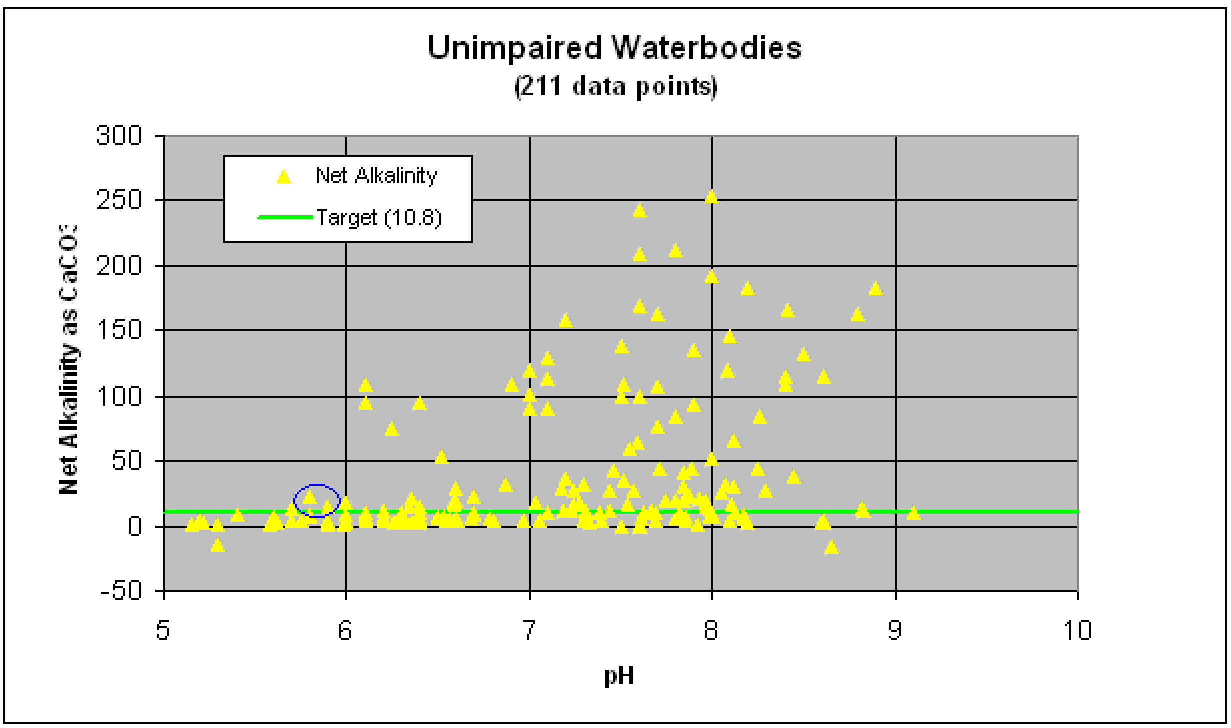

Figure C-2 pH and Net Alkalinity for Unimpaired Waterbodies in Tennessee
(acidity or total alkalinity was not detected; 0.5 x detection limit used for non detects)

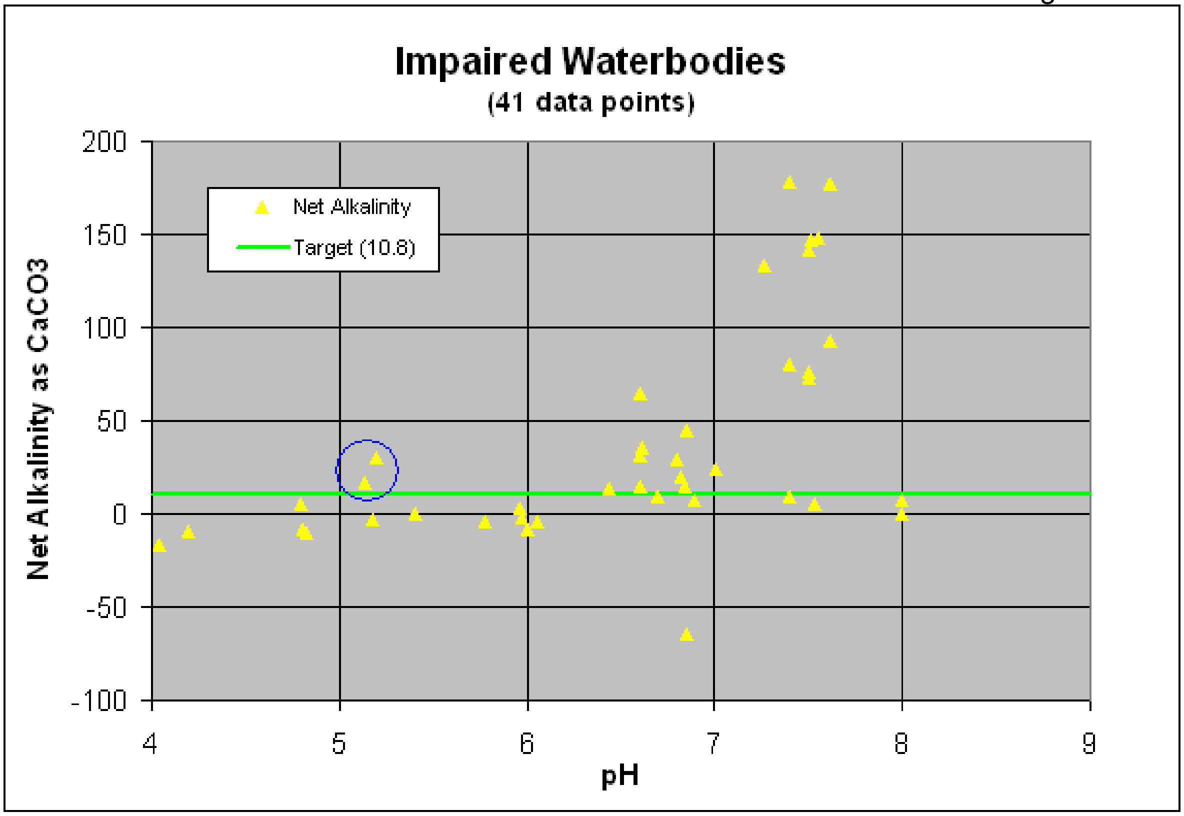

Figure C-3 pH and Net Alkalinity for Impaired Waterbodies in Tenneessee
(no non-detects for either acidity or total alkalinity)

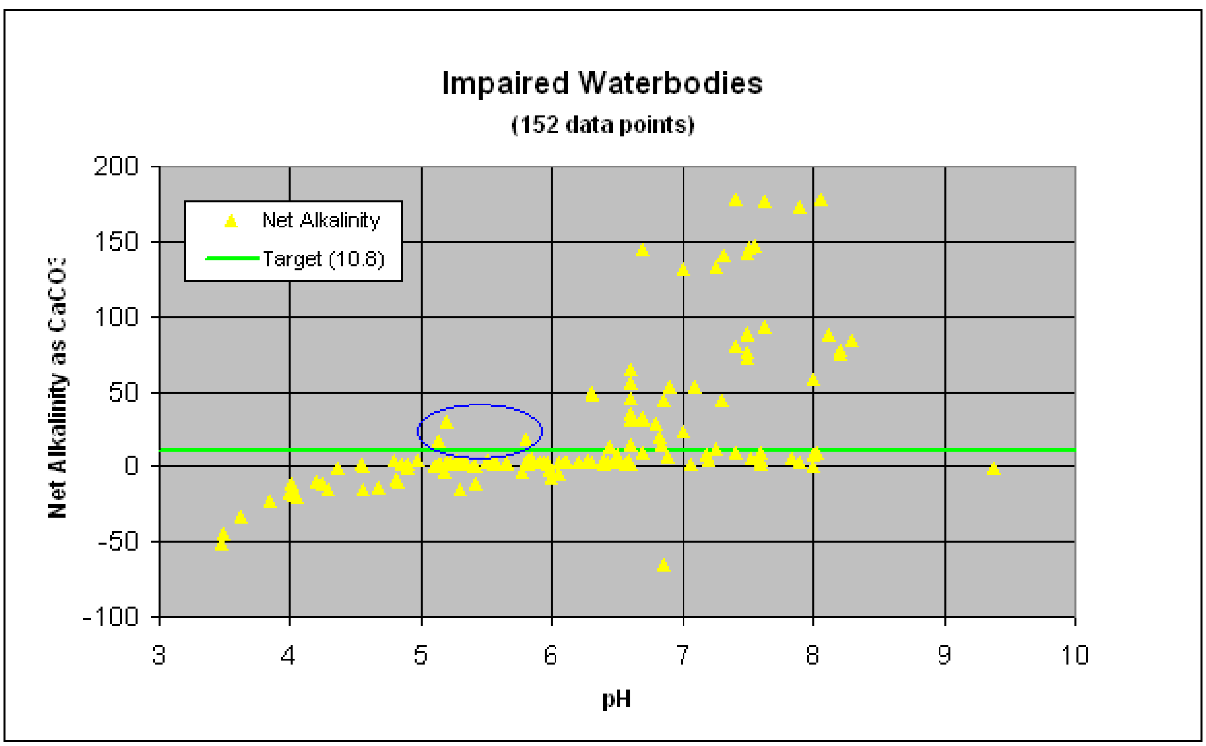

Figure C-4 pH and Net Alkalinity for Impaired Waterbodies in Tenneessee
(acidity or total alkalinity was not detected; 0.5 x detection limit used for non detects)

APPENDIX D

**Development of Water Quality Criteria
for
Hardness-Dependent Metals**

D.1 Introduction

The Final 2006 303(d) list (TDEC, 2006) identified the East Fork Obey River, from Rockcastle Creek to the headwaters, and the West Fork Obey River, from Cub Creek to the headwaters, as not fully supporting designated use classifications due, in part, to metals associated with abandoned mining and resource extraction. Three of the designated use classifications for the listed segments of the East and West Fork Obey River (domestic water supply, fish and aquatic life, and recreation) have numerical criteria for metals. Water quality criteria for applicable use classifications are established in *State of Tennessee Water Quality Standards, Chapter 1200-4-3 General Water Quality Criteria, January, 2004* (TDEC, 2004).

D.2 Numerical Criteria for the Drinking Water Supply & Recreation Use Classifications

Water quality criteria for the drinking water supply and recreation use classifications contain a single expression of allowable magnitude and are associated with the protection of human health from long-term (chronic) effects. Criteria for these use classifications are summarized in Table D-1.

Table D-1 Metals Criteria for the Drinking Water Supply & Recreation Use Classifications

Metal (Total Recoverable)	Drinking Water Supply	Recreation	
		Water & Organisms	Organisms Only
	[μg/l]	[μg/l]	[μg/l]
Arsenic	10	10	10
Cadmium	5	—	—
Chromium	100	—	—
Copper	—	—	—
Lead	5	—	—
Nickel	100	610	4600
Zinc	—	—	—

D.3 Numerical Criteria for the Fish & Aquatic Life Use Classifications

Water quality criteria for the fish & aquatic life use classification contain two expressions of allowable magnitude: a Criteria Maximum Concentration (CMC) to protect against short-term (acute) effects and a Criteria Continuous Concentration (CCC) to protect against long-term (chronic) effects. In accordance with the guidance in *Technical Support Document For Water Quality-based Toxics Control* (USEPA, 1991b), fish & aquatic life criteria are interpreted to mean that the 1-hour average exposure should not exceed the CMC and the 4-day average exposure should not exceed the CCC. Excursions of CMCs & CCCs should not exceed a frequency of once every three years.

CMCs & CCCs for certain metals (including cadmium, chromium, copper, lead, nickel, and zinc) are a function of water hardness (as $CaCO_3$). In the toxicity tests used to derive metals criteria for aquatic life, some fraction of the metal was dissolved and some fraction bound to particulate matter. The criteria concentrations resulting from these tests were expressed as total recoverable metal. In consideration of the premise that the dissolved fraction of metal more closely approximates the biologically available fraction, conversion factors were developed to predict how different the criteria would be if they had been based on measurements of the dissolved concentrations in the toxicity tests used to develop criteria.

As effluents from point and nonpoint source discharges mix with receiving water, the chemical properties of the mixture will determine the fraction of metal that is dissolved and the fraction that is in particulate form. Factors that influence the dissolved to total recoverable metal ratio include temperature , hardness, pH, concentration of binding sites (such as total suspended solids), and concentrations of other materials that compete for binding sites. Criteria (CMCs & CCCs) can be related to effluent discharges through the use of metals translators.

Cadmium, chromium, copper, lead, nickel, and zinc criteria, as well as the instream total recoverable concentrations (ITRCs) required to comply with these criteria, were calculated for each sample date in accordance with *State of Tennessee Water Quality Standards* using the methodology described in *The Metals Translator: Guidance For Calculating A Total Recoverable Permit Limit From a Dissolved Criterion*, EPA 823-B-96-007, June 1996 (USEPA 1996) (see Tables D-2 thru D-7).

Table D-2 Monitoring Data and Calculations for Cadmium

Station ID	Date	Time	TSS [mg/l]	Hardness (as $CaCO_3$) [mg/l]	CMC_{TR}	CMC_{DIS}	$ITRC_{Acute}$	CCC_{TR}	CCC_{DIS}	$ITRC_{Chronic}$	Observed Value
EFOBE039.6OV	7/11/00	0923	10								1U
	8/15/00	0914	10	115.0	2.46	2.31	9.14	0.30	0.27	1.07	1U
	9/20/00	0915	10	132.0	2.83	2.64	10.45	0.33	0.30	1.18	1U
	10/17/00	0842	10	105.0	2.24	2.11	8.36	0.28	0.25	1.01	1U
	11/15/00	0853	10	74.3	1.58	1.51	5.97	0.22	0.20	0.79	1U
	12/12/00	0855	10	83.0	1.77	1.68	6.65	0.24	0.22	0.86	1U
	1/23/01	0910	10	66.0	1.40	1.34	5.32	0.20	0.18	0.73	1U
	2/21/01	0850	10	38.0	0.80	0.79	3.11	0.13	0.13	0.50	2
	3/21/01	0853	10	57.0	1.20	1.17	4.62	0.18	0.17	0.66	1U
	5/17/01	1200	10	78.0	1.66	1.58	6.26	0.23	0.21	0.82	1U
	6/20/01	1145	10	84.0	1.79	1.70	6.73	0.24	0.22	0.86	1U
	12/10/03	0935	10	46.2	0.97	0.95	3.76	0.15	0.14	0.57	1U
	1/13/04	0925	10	24.2	0.50	0.51	2.00	0.09	0.09	0.36	1U
	2/17/04	0928	10	19.4	0.40	0.41	1.62	0.08	0.08	0.31	1U
	3/17/04	0928	10	25.6	0.53	0.53	2.12	0.10	0.10	0.38	1U
	4/19/04	0935	10	23.1	0.48	0.48	1.91	0.09	0.09	0.35	1U
	5/18/04	0940	10	20.8	0.43	0.44	1.73	0.08	0.08	0.33	1U
	6/23/04	0930	10	56.0	1.18	1.15	4.54	0.18	0.16	0.65	1U
	8/17/04	0905	10	32.6	0.68	0.68	2.68	0.12	0.11	0.45	1U
WFOBE009.5OV	12/10/03	1015	10	115.0	2.46	2.31	9.14	0.30	0.27	1.07	1U
	1/13/04	1000	10	141.0	3.02	2.81	11.14	0.35	0.31	1.24	1U
	2/17/04	1000	10	139.0	2.98	2.77	10.98	0.35	0.31	1.22	1U
	3/17/04	1012	10	129.0	2.76	2.58	10.22	0.33	0.29	1.16	1U
	4/19/04	1010	10	132.0	2.83	2.64	10.45	0.33	0.30	1.18	1U
	5/18/04	1020	10	121.0	2.59	2.42	9.60	0.31	0.28	1.11	1U
	6/23/04	1005	10	199.0	4.29	3.93	15.56	0.45	0.40	1.57	1U
	8/17/04	0940	10	104.0	2.22	2.09	8.29	0.28	0.25	1.00	1U

Table D-3 Monitoring Data and Calculations for Chromium

Station ID	Date	Time	TSS [mg/l]	Hardness (as $CaCO_3$) [mg/l]	CMC_{TR}	CMC_{DIS}	$ITRC_{Acute}$	CCC_{TR}	CCC_{DIS}	$ITRC_{Chronic}$	Observed Value
EFOBE039.6OV	7/11/00	0923	10								1U
	8/15/00	0914	10	115.0	2021.71	638.86	3158.54	96.63	83.10	410.86	1U
	9/20/00	0915	10	132.0	2263.38	715.23	3536.10	108.18	93.04	459.97	1U
	10/17/00	0842	10	105.0	1876.56	592.99	2931.76	89.69	77.14	381.36	1U
	11/15/00	0853	10	74.3	1413.67	446.72	2208.59	67.57	58.11	287.29	1U
	12/12/00	0855	10	83.0	1547.86	489.12	2418.24	73.98	63.63	314.56	1U
	1/23/01	0910	10	66.0	1282.96	405.42	2004.39	61.32	52.74	260.73	1U
	2/21/01	0850	10	38.0	816.30	257.95	1275.32	39.02	33.55	165.89	2
	3/21/01	0853	10	57.0	1137.81	359.55	1777.61	54.38	46.77	231.23	1U
	5/17/01	1200	10	78.0	1471.07	464.86	2298.27	70.31	60.47	298.96	1U
	6/20/01	1145	10	84.0	1563.12	493.95	2442.08	74.71	64.25	317.66	1U
	12/10/03	0935	10	46.2	957.96	302.72	1496.64	45.79	39.38	194.68	1U
	1/13/04	0925	10	24.2	564.10	178.25	881.29	26.96	23.19	114.64	1U
	2/17/04	0928	10	19.4	470.67	148.73	735.33	22.50	19.35	95.65	1U
	3/17/04	0928	10	25.6	590.69	186.66	922.83	28.23	24.28	120.04	1U
	4/19/04	0935	10	23.1	543.01	171.59	848.35	25.95	22.32	110.35	1U
	5/18/04	0940	10	20.8	498.31	157.47	778.52	23.82	20.48	101.27	1U
	6/23/04	0930	10	56.0	1121.43	354.37	1752.03	53.60	46.10	227.90	1U
	8/17/04	0905	10	32.6	720.00	227.52	1124.86	34.41	29.60	146.32	1U
WFOBE009.5OV	12/10/03	1015	10	115.0	2021.71	638.86	3158.54	96.63	83.10	410.86	1U
	1/13/04	1000	10	141.0	2389.01	754.93	3732.38	114.19	98.20	485.51	1U
	2/17/04	1000	10	139.0	2361.22	746.15	3688.96	112.86	97.06	479.86	1U
	3/17/04	1012	10	129.0	2221.16	701.89	3470.15	106.16	91.30	451.39	1U
	4/19/04	1010	10	132.0	2263.38	715.23	3536.10	108.18	93.04	459.97	1U
	5/18/04	1020	10	121.0	2107.70	666.03	3292.88	100.74	86.64	428.34	1U
	6/23/04	1005	10	199.0	3167.88	1001.05	4949.21	151.41	130.22	643.79	1U
	8/17/04	0940	10	104.0	1861.91	588.36	2908.88	88.99	76.53	378.39	1U

Table D-4 Monitoring Data and Calculations for Copper

Station ID	Date	Time	TSS [mg/l]	Hardness (as $CaCO_3$) [mg/l]	CMC_{TR}	CMC_{DIS}	$ITRC_{Acute}$	CCC_{TR}	CCC_{DIS}	$ITRC_{Chronic}$	Observed Value
EFOBE039.6OV	7/11/00	0923	10								1U
	8/15/00	0914	10	115.0	15.97	15.33	44.19	10.51	10.09	29.09	3
	9/20/00	0915	10	132.0	18.18	17.46	50.32	11.83	11.35	32.72	1
	10/17/00	0842	10	105.0	14.66	14.07	40.56	9.73	9.34	26.91	2
	11/15/00	0853	10	74.3	10.58	10.16	29.28	7.24	6.95	20.03	3
	12/12/00	0855	10	83.0	11.75	11.28	32.50	7.96	7.64	22.01	2
	1/23/01	0910	10	66.0	9.46	9.09	26.19	6.54	6.28	18.10	2
	2/21/01	0850	10	38.0	5.63	5.40	15.57	4.08	3.92	11.29	4
	3/21/01	0853	10	57.0	8.24	7.91	22.81	5.77	5.54	15.97	1U
	5/17/01	1200	10	78.0	11.08	10.63	30.65	7.54	7.24	20.88	1
	6/20/01	1145	10	84.0	11.88	11.40	32.87	8.04	7.72	22.24	2
	12/10/03	0935	10	46.2	6.76	6.49	18.71	4.82	4.63	13.34	1U
	1/13/04	0925	10	24.2	3.68	3.53	10.18	2.78	2.66	7.68	1U
	2/17/04	0928	10	19.4	2.99	2.87	8.26	2.30	2.21	6.36	1U
	3/17/04	0928	10	25.6	3.88	3.72	10.73	2.91	2.80	8.06	1U
	4/19/04	0935	10	23.1	3.52	3.38	9.74	2.67	2.56	7.38	3
	5/18/04	0940	10	20.8	3.19	3.06	8.82	2.44	2.34	6.75	1U
	6/23/04	0930	10	56.0	8.11	7.78	22.43	5.68	5.46	15.73	4
	8/17/04	0905	10	32.6	4.87	4.67	13.47	3.58	3.44	9.91	3
WFOBE009.5OV	12/10/03	1015	10	115.0	15.97	15.33	44.19	10.51	10.09	29.09	1U
	1/13/04	1000	10	141.0	19.35	18.58	53.54	12.51	12.01	34.62	1
	2/17/04	1000	10	139.0	19.09	18.33	52.83	12.36	11.87	34.20	1U
	3/17/04	1012	10	129.0	17.79	17.08	49.24	11.60	11.13	32.09	1U
	4/19/04	1010	10	132.0	18.18	17.46	50.32	11.83	11.35	32.72	2
	5/18/04	1020	10	121.0	16.75	16.08	46.36	10.98	10.54	30.38	1U
	6/23/04	1005	10	199.0	26.77	25.70	74.08	16.80	16.12	46.47	4
	8/17/04	0940	10	104.0	14.53	13.95	40.19	9.65	9.26	26.69	4

Table D-5 Monitoring Data and Calculations for Lead

Station ID	Date	Time	TSS [mg/l]	Hardness (as $CaCO_3$) [mg/l]	CMC_{TR}	CMC_{DIS}	$ITRC_{Acute}$	CCC_{TR}	CCC_{DIS}	$ITRC_{Chronic}$	Observed Value
EFOBE039.6OV	7/11/00	0923	10								1U
	8/15/00	0914	10	115.0	97.54	75.17	408.76	3.80	2.93	15.93	1
	9/20/00	0915	10	132.0	116.26	87.26	474.48	4.53	3.40	18.49	1U
	10/17/00	0842	10	105.0	86.88	68.10	370.32	3.39	2.65	14.43	1U
	11/15/00	0853	10	74.3	55.94	46.67	253.76	2.18	1.82	9.89	1U
	12/12/00	0855	10	83.0	64.40	52.69	286.53	2.51	2.05	11.17	1U
	1/23/01	0910	10	66.0	48.11	40.97	222.76	1.87	1.60	8.68	1U
	2/21/01	0850	10	38.0	23.82	22.20	120.73	0.93	0.87	4.70	1U
	3/21/01	0853	10	57.0	39.92	34.84	189.47	1.56	1.36	7.38	1U
	5/17/01	1200	10	78.0	59.51	49.22	267.67	2.32	1.92	10.43	1U
	6/20/01	1145	10	84.0	65.39	53.39	290.31	2.55	2.08	11.31	1U
	12/10/03	0935	10	46.2	30.55	27.60	150.10	1.19	1.08	5.85	1U
	1/13/04	0925	10	24.2	13.41	13.38	72.77	0.52	0.52	2.84	1U
	2/17/04	0928	10	19.4	10.12	10.43	56.69	0.39	0.41	2.21	1U
	3/17/04	0928	10	25.6	14.41	14.26	77.53	0.56	0.56	3.02	1U
	4/19/04	0935	10	23.1	12.64	12.70	69.05	0.49	0.49	2.69	1U
	5/18/04	0940	10	20.8	11.06	11.28	61.34	0.43	0.44	2.39	2
	6/23/04	0930	10	56.0	39.03	34.17	185.80	1.52	1.33	7.24	1U
	8/17/04	0905	10	32.6	19.60	18.70	101.71	0.76	0.73	3.96	1U
WFOBE009.5OV	12/10/03	1015	10	115.0	97.54	75.17	408.76	3.80	2.93	15.93	1U
	1/13/04	1000	10	141.0	126.44	93.68	509.43	4.93	3.65	19.85	1U
	2/17/04	1000	10	139.0	124.16	92.25	501.65	4.84	3.60	19.55	1U
	3/17/04	1012	10	129.0	112.90	85.12	462.85	4.40	3.32	18.04	1U
	4/19/04	1010	10	132.0	116.26	87.26	474.48	4.53	3.40	18.49	1U
	5/18/04	1020	10	121.0	104.07	79.43	431.90	4.06	3.10	16.83	1U
	6/23/04	1005	10	199.0	196.05	135.42	736.37	7.64	5.28	28.70	1U
	8/17/04	0940	10	104.0	85.82	67.40	366.49	3.34	2.63	14.28	1U

Table D-6 Monitoring Data and Calculations for Nickel

Station ID	Date	Time	TSS [mg/l]	Hardness (as $CaCO_3$) [mg/l]	CMC_{TR}	CMC_{DIS}	$ITRC_{Acute}$	CCC_{TR}	CCC_{DIS}	$ITRC_{Chronic}$	Observed Value
EFOBE039.6OV	7/11/00	0923	10								10U
	8/15/00	0914	10	115.0	528.06	527.01	1219.01	58.71	58.53	58.71	10U
	9/20/00	0915	10	132.0	593.39	592.20	1369.82	65.97	65.78	65.97	10U
	10/17/00	0842	10	105.0	488.95	487.97	1128.71	54.36	54.20	54.36	10U
	11/15/00	0853	10	74.3	364.91	364.18	842.39	40.57	40.45	40.57	10U
	12/12/00	0855	10	83.0	400.75	399.95	925.12	44.56	44.42	44.56	10U
	1/23/01	0910	10	66.0	330.12	329.46	762.07	36.70	36.59	36.70	10U
	2/21/01	0850	10	38.0	206.93	206.52	477.70	23.01	22.94	23.01	10U
	3/21/01	0853	10	57.0	291.61	291.03	673.18	32.42	32.32	32.42	10U
	5/17/01	1200	10	78.0	380.23	379.47	877.75	42.27	42.15	42.27	10U
	6/20/01	1145	10	84.0	404.83	404.02	934.54	45.01	44.87	45.01	10U
	12/10/03	0935	10	46.2	244.13	243.64	563.57	27.14	27.06	27.14	10U
	1/13/04	0925	10	24.2	141.27	140.98	326.11	15.71	15.66	15.71	10U
	2/17/04	0928	10	19.4	117.17	116.94	270.48	13.03	12.99	13.03	10U
	3/17/04	0928	10	25.6	148.15	147.85	342.00	16.47	16.42	16.47	10U
	4/19/04	0935	10	23.1	135.82	135.54	313.53	15.10	15.05	15.10	10U
	5/18/04	0940	10	20.8	124.28	124.04	286.91	13.82	13.78	13.82	10U
	6/23/04	0930	10	56.0	287.28	286.70	663.17	31.94	31.84	31.94	10U
	8/17/04	0905	10	32.6	181.77	181.40	419.60	20.21	20.15	20.21	10U
WFOBE009.5OV	12/10/03	1015	10	115.0	528.06	527.01	1219.01	58.71	58.53	135.39	10U
	1/13/04	1000	10	141.0	627.44	626.19	1448.43	69.76	69.55	160.88	10U
	2/17/04	1000	10	139.0	619.90	618.66	1431.03	68.92	68.71	158.94	10U
	3/17/04	1012	10	129.0	581.96	580.80	1343.44	64.70	64.51	149.21	10U
	4/19/04	1010	10	132.0	593.39	592.20	1369.82	65.97	65.78	152.14	10U
	5/18/04	1020	10	121.0	551.28	550.18	1272.61	61.29	61.11	141.35	10U
	6/23/04	1005	10	199.0	839.78	838.10	1938.60	93.37	93.09	215.32	10U
	8/17/04	0940	10	104.0	485.00	484.03	1119.61	53.92	53.76	124.35	10U

Table D-7 Monitoring Data and Calculations for Zinc

Station ID	Date	Time	TSS [mg/l]	Hardness (as $CaCO_3$) [mg/l]	CMC_{TR}	CMC_{DIS}	$ITRC_{Acute}$	CCC_{TR}	CCC_{DIS}	$ITRC_{Chronic}$	Observed Value
EFOBE039.6OV	7/11/00	0923	10								2
	8/15/00	0914	10	115.0	134.88	131.91	458.04	134.88	132.99	461.79	13
	9/20/00	0915	10	132.0	151.59	148.26	514.80	151.59	149.47	519.01	12
	10/17/00	0842	10	105.0	124.87	122.13	424.06	124.87	123.13	427.53	14
	11/15/00	0853	10	74.3	93.15	91.11	316.35	93.15	91.85	318.94	13
	12/12/00	0855	10	83.0	102.32	100.07	347.47	102.32	100.89	350.31	16
	1/23/01	0910	10	66.0	84.26	82.41	286.14	84.26	83.08	288.48	14
	2/21/01	0850	10	38.0	52.78	51.62	179.24	52.78	52.04	180.70	4
	3/21/01	0853	10	57.0	74.42	72.78	252.72	74.42	73.37	254.78	7
	5/17/01	1200	10	78.0	97.07	94.94	329.65	97.07	95.71	332.34	9
	6/20/01	1145	10	84.0	103.36	101.09	351.01	103.36	101.91	353.88	4
	12/10/03	0935	10	46.2	62.28	60.91	211.51	62.28	61.41	213.24	9
	1/13/04	0925	10	24.2	36.01	35.22	122.29	36.01	35.51	123.29	4
	2/17/04	0928	10	19.4	29.86	29.20	101.40	29.86	29.44	102.23	4
	3/17/04	0928	10	25.6	37.77	36.94	128.26	37.77	37.24	129.31	6
	4/19/04	0935	10	23.1	34.62	33.86	117.56	34.62	34.13	118.52	8
	5/18/04	0940	10	20.8	31.67	30.98	107.57	31.67	31.23	108.45	11
	6/23/04	0930	10	56.0	73.31	71.70	248.95	73.31	72.28	250.99	6
	8/17/04	0905	10	32.6	46.35	45.33	157.41	46.35	45.70	158.70	1U
WFOBE009.5OV	12/10/03	1015	10	115.0	134.88	131.91	458.04	134.88	132.99	461.79	2
	1/13/04	1000	10	141.0	160.31	156.78	544.39	160.31	158.06	548.85	1
	2/17/04	1000	10	139.0	158.38	154.89	537.84	158.38	156.16	542.24	1U
	3/17/04	1012	10	129.0	148.67	145.40	504.87	148.67	146.59	509.00	2
	4/19/04	1010	10	132.0	151.59	148.26	514.80	151.59	149.47	519.01	2
	5/18/04	1020	10	121.0	140.82	137.72	478.21	140.82	138.85	482.13	1
	6/23/04	1005	10	199.0	214.65	209.93	728.95	214.65	211.65	734.91	1U
	8/17/04	0940	10	104.0	123.87	121.14	420.64	123.87	122.13	424.08	1

Fish & aquatic life criteria and ITRCs for copper in Level IV ecoregions 68a and 68c were calculated using the following procedure (calculations for cadmium, chromium, lead, nickel and zinc are similar):

1) The total recoverable Criterion Maximum Concentration (CMC_{TR}) and Criterion Continuous Concentration (CCC_{TR}) at laboratory conditions are calculated using the equations:

$$CMC_{TR} = \exp\{m_A [\ln (\text{hardness})] + b_A\}$$

$$CCC_{TR} = \exp\{m_C [\ln (\text{hardness})] + b_C\}$$

for copper:

$$CMC_{TR} = \exp\{0.9422 [\ln (\text{hardness})] - 1.7\}$$

$$CCC_{TR} = \exp\{0.8545 [\ln (\text{hardness})] - 1.702\}$$

for sampling event at EFOBE039.0OV on 8/15/00:

$$CMC_{TR} = \exp\{0.9422 [\ln (115.0)] - 1.7\} = 15.97\ \mu g/l$$

$$CCC_{TR} = \exp\{0.8545 [\ln (115.0)] - 1.702\} = 10.51\ \mu g/l$$

2) The dissolved Criterion Maximum Concentration (CMC_{DIS}) and Criterion Continuous Concentration (CCC_{DIS}) at laboratory conditions are calculated for by applying the Acute Conversion Factor (ACF) and Chronic Conversion Factor (CCF) respectively:

$$CMC_{DIS} = (CMC_{TR})\ (ACF)$$

$$CCC_{DIS} = (CCC_{TR})\ (CCF)$$

for copper:

$$ACF = 0.96$$

$$CCF = 0.96$$

therefore:

$$CMC_{DIS} = (1.6)\ (0.96) = 15.33\ \mu g/l$$

$$CCC_{DIS} = (1.3)\ (0.96) = 10.09\ \mu g/l$$

3) The metals translator is defined as the fraction of total recoverable metal in the downstream water, after mixing with effluents, that is dissolved.

The metals translator is calculated using the equation:

$$\text{Translator} = \frac{1}{1 + \{ [K_{po}] \ [TSS^{(1+a)}] \ [10^{-6}] \}}$$

for copper:

$$\text{Translator}_{Ni} = \frac{1}{1 + \{ [1.04 \times 10^{6}] \ [10^{(1 - 0.7436)}] \ [10^{-6}] \}} = 0.347$$

4) The instream total recoverable concentration (ITRC) that corresponds to the dissolved criterion is expressed as:

$$\text{ITRC} = (\text{Water Quality Criterion})_{dissolved} \ (1/\text{Translator})$$

The ITRCs are calculated by applying the translator to the CMC_{DIS} and the CCC_{DIS}:

$$\text{ITRC}_{acute} = \frac{CMC_{DIS}}{\text{Translator}}$$

$$\text{ITRC}_{chronic} = \frac{CCC_{DIS}}{\text{Translator}}$$

for copper:

$$\text{ITRC}_{acute} = \frac{15.33}{0.347} = 44.19 \ \mu g/l$$

$$\text{ITRC}_{chronic} = \frac{10.09}{0.347} = 29.09 \ \mu g/l$$

5) The observed value for the sample date (3 μg/l) is less than both the acute and chronic ITRC. Therefore, there is no exceedance of water quality criteria on this date.

APPENDIX E

Load Duration Curve Development
and
Determination of Daily Loading

The TMDL process quantifies the amount of a pollutant that can be assimilated in a waterbody, identifies the sources of the pollutant, and recommends regulatory or other actions to be taken to achieve compliance with applicable water quality standards based on the relationship between pollution sources and in-stream water quality conditions. A TMDL can be expressed as the sum of all point source loads (Waste Load Allocations), nonpoint source loads (Load Allocations), and an appropriate margin of safety (MOS) that takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$TMDL = \Sigma \text{ WLAs} + \Sigma \text{ LAs} + MOS$$

The objective of a TMDL is to allocate loads among all of the known pollutant sources throughout a watershed so that appropriate control measures can be implemented and water quality standards achieved. 40 CFR §130.2 (i) (http://www.epa.gov/epacfr40/chapt-I.info/chi-toc.htm) states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measure.

Net alkalinity and individual metal TMDLs, WLAs, and LAs were developed for impaired subwatersheds and drainage areas in the Obey River Watershed using Load Duration Curves (LDCs). Daily Loads for TMDLs, WLAs, and LAs are expressed as a function of daily mean in-stream flow (daily loading function).

E.1 Development of Flow Duration Curves

A flow duration curve is a cumulative frequency graph, constructed from historic flow data at a particular location, that represents the percentage of time a particular flow rate is equaled or exceeded. Flow duration curves are developed for a waterbody from daily discharges of flow over a period of record. In general, there is a higher level of confidence that curves derived from data over a long period of record correctly represent the entire range of flow. The preferred method of flow duration curve computation uses daily mean data from U.S. Geological Survey (USGS) continuous-record stations (http://waterdata.usgs.gov/tn/nwis/sw) located on the waterbody of interest. For ungaged streams, alternative methods must be used to estimate daily mean flow. These include: 1) regression equations (using drainage area as the independent variable) developed from continuous record stations in the same ecoregion; 2) drainage area extrapolation of data from a nearby continuous-record station of similar size and topography; and 3) calculation of daily mean flow using a dynamic computer model, such as the Loading Simulation Program C++ (LSPC).

Flow duration curves for pH-impaired waterbodies in the Obey River watershed were derived from LSPC hydrologic simulations based on parameters derived from calibration at USGS Station No. 03408500, located on New River at New River, Tennessee, in the South Fork Cumberland River watershed (see Appendix F for details of calibration). For example, a flow-duration curve for East Fork Obey River at RM 39.0 was constructed using simulated daily mean flow for the period from 10/1/95 through 9/30/05 (RM 39.0 corresponds to the location of monitoring station EFOBE039.0OV). This flow duration curve is shown in Figure E-1 and represents the cumulative distribution of daily discharges arranged to show percentage of time specific flows were exceeded during the period of record (the highest daily mean flow during this period is exceeded 0% of the time and the lowest daily mean flow is equaled or exceeded 100% of the time). The flow duration curve for other impaired waterbodies was derived using a similar procedure.

E.2 Development of Load Duration Curves

When a water quality target concentration is applied to the flow duration curve, the resulting load duration curve (LDC) represents the allowable pollutant loading in a waterbody over the entire range of flow. The target net alkalinity load duration curve for the Obey River watershed was developed from the flow duration curve for East Fork Obey River developed in Section E.1. The target curve can be applied to all impaired waterbodies in the Obey River watershed because it was developed on a unit drainage area basis. The net alkalinity target concentration of 10.8 mg/L was applied to each of the ranked flows used to generate the flow duration curve and the results were plotted. The net alkalinity target load corresponding to each ranked daily mean flow is:

Target Load = (10.8) x (Q/A) x (UCF)

where: Q = daily mean flow
A = drainage area
UCF = the required unit conversion factor

The target net alkalinity load duration curve, on a unit drainage area basis, is presented in Figures E-2 and E-3. Figure E-2 is presented in semi-log scale format while Figure E-3 is presented in non-log scale format. Because the calculated net alkalinity of the Obey River watershed can be negative and negative values cannot be plotted on a log or semi-log scale format, the non-log scale format will be used for net alkalinity load duration curves in this TMDL.

The target load duration curve for each metal was developed similar to the target load duration curve for net alkalinity. The appropriate target concentration for each metal was applied to each of the ranked flows used to generate the flow duration curve and the results were plotted (Figures E-4 thru E-6).

Pollutant monitoring data, plotted on the LDC, provides a visual depiction of stream water quality as well as the frequency and magnitude of any exceedances. Load duration curve intervals can be grouped into several broad categories or zones, in order to provide additional insight about conditions and patterns associated with the impairment. For example, the duration curve could be divided into four zones: high flows (exceeded 0-10% of the time), moist conditions (10-40%), median or mid-range flows (40-70%), and low flows (70-100%). Impairments observed in the low flow zone typically indicate the influence of point sources, while those further left on the LDC (representing zones of higher flow) generally reflect potential nonpoint source contributions (Stiles, 2003).

Load duration curves for specific monitoring locations were developed using the following procedure (East Fork Obey River is used as an example):

1. Daily loads were calculated for each of the water quality samples collected at monitoring station EFOBE039.0OV (ref.: Table B-1) by multiplying the sample concentration by the daily mean flow for the sampling date and the required unit conversion factor, and dividing by the subwatershed drainage area. EFOBE039.0OV was selected for LDC analysis because it was the monitoring station on the impaired portion of East Fork Obey River with the pH and metal concentration data available.

Note: *In order to be consistent for all analyses, the derived daily mean flow was used to compute sampling data loads, even if measured ("instantaneous") flow data was available for some sampling dates.*

Example – 1/23/01 sampling event:
Modeled Flow = 116.49 cfs
Concentration = 484 μg/L
Area = 21,701.1 acres = 33.91 mi^2
Daily Load = 8.97 lbs iron/day/mi^2

2. Using the flow duration curves developed in E.1, the "percent of days the flow was exceeded" (PDFE) was determined for each sampling event. Each sample load was then plotted on the load duration curves developed in Step 1 according to the PDFE. The resulting iron load duration curve is shown in Figure E-8.

Example – 1/23/01 sampling event:
Modeled Flow = 116.49 cfs
PDFE = 14.4%

LDCs for other metals and other impaired waterbodies were derived in a similar manner and are shown in Figures E-7 through E-10.

E.3 Development of WLAs, LAs, and MOS

As previously discussed, a TMDL can be expressed as the sum of all point source loads (WLAs), nonpoint source loads (LAs), and an appropriate margin of safety (MOS) that takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$\text{TMDL} = \Sigma \text{ WLAs} + \Sigma \text{ LAs} + \text{MOS}$$

As stated in Section 7.2, an explicit MOS, equal to 10% of the water quality targets (ref.: Section 4.0), was utilized for determination of the percent load reductions necessary to achieve the WLAs and LAs:

Instantaneous Maximum for Iron (East Fork Obey only)
Target – MOS = (300 μg/L) – (30 μg/L) = 270 μg/L
Instantaneous Maximum for Iron (all other waterbodies)
Target – MOS = (1000 μg/L) – (100 μg/L) = 900 μg/L
Instantaneous Maximum for Manganese (East Fork Obey only)
Target – MOS = (50 μg/L) – (5 μg/L) = 45 μg/L
Instantaneous Maximum for Aluminum (East Fork Obey only)
Target – MOS = (200 μg/L) – (20 μg/L) = 180 μg/L

E.4 Daily Load Calculations

Each of the terms in the equation above can be derived sequentially:

TMDL = (Target Concentration) x (Q) x (UCF)

where: Target Concentration = water quality criterion
Q = daily mean flow
UCF = the required unit conversion factor

Using East Fork Obey River at Mile 39.0 as an example for iron:

$TMDL_{EFO39} = (300\ \mu g/L) \times (Q) \times (UCF)$

$\mathbf{TMDL_{EFO39} = 1.61 \times Q\ (lbs/day)}$

$MOS_{EFO39} = TMDL \times 0.10$

$\mathbf{MOS_{EFO39} = 0.161 \times Q\ (lbs/day)}$

By rearranging the equation in section E.4 and expressing on a unit area basis:

$\Sigma\ LAs = (TMDL - MOS - \Sigma\ WLAs) / DA$

where: DA = waterbody drainage area (acres)

Since there are no permitted point sources contributing at Mile 39.0, WLA = 0. Therefore:

$LA_{EFO39} = \{(1.61 \times Q) - (0.161 \times Q)\} / (21{,}701.1)$

$\mathbf{LA_{EFO39} = (6.69 \times 10^{-5}) \times Q\ (lbs/day/ac)}$

For segment _2000, permitted point sources exist and the applicable WLA must be calculated:

$WLA = \{(Permit\ Limit) \times (Q_2) \times (UCF)\}$

where: Q_2 = daily mean flow for combined point sources
UCF = the required unit conversion factor

$WLA_{EFO2000} = (3\ mg/L \times Q_2 \times UCF)$

$\mathbf{WLA_{EFO2000} = 16.1 \times Q_2\ (lbs/day)}$

Since there are permitted point sources contributing to segment _2000:

$LA_{EFO2000} = \{(1.61 \times Q) - (0.161 \times Q) - (16.1 \times Q_2)\} / (21{,}701.1)$

$\mathbf{LA_{EFO2000} = \{(6.69 \times 10^{-5}) \times Q\} - \{(1.49 \times 10^{-4}) \times Q_2\}\ (lbs/day/ac)}$

TMDLs, WLAs, & LAs for impaired waterbodies in the Obey River watershed are summarized in Table E-5.

E.5 Calculation of Percent Load Reduction Goals (PLRGs)

In order to facilitate implementation, corresponding percent reductions in loading required to decrease existing, in-stream loads to TMDL target levels (percent load reduction goals) were calculated. The following example is from East Fork Obey River at Mile 39.0.

1. For cases where the existing load exceeded the target maximum load at a particular PDFE, the reduction required to reduce the sample load to the target load was calculated.

   Example – 1/23/01 sampling event:
   Target Concentration = 300 μg/L
   Measured Concentration = 484 μg/L
   Reduction to Target = 38.0%

2. The 90th percentile value for all of the iron sampling data at the East Fork Obey River monitoring station was determined. If the 90th percentile value exceeded the target maximum iron concentration, the reduction required to reduce the 90th percentile value to the target maximum concentration was calculated.

   Example: *Target Concentration = 300 μg/L*
   90th Percentile Concentration = 520 μg/L
   Reduction to Target = 42.3%

Percent load reduction goals for iron, manganese, and aluminum for other impaired waterbodies were derived in a similar manner and are shown in Tables E-1 through E-4. TMDLs, WLAs, LAs, and PLRGs for impaired waterbodies in the Obey River watershed are summarized in Table E-5.

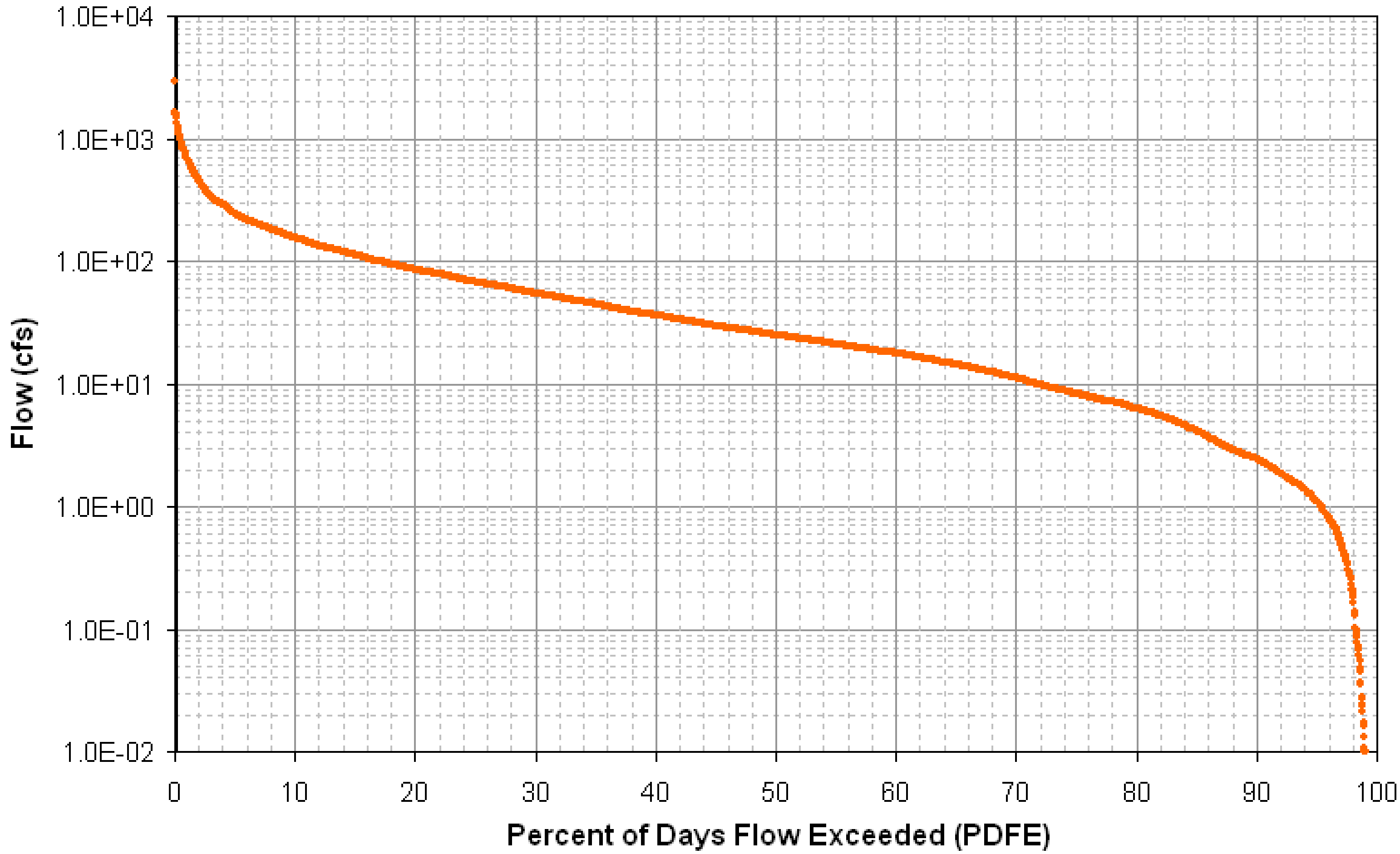

Figure E-1 Flow Duration Curve for East Fork Obey River at RM39.0

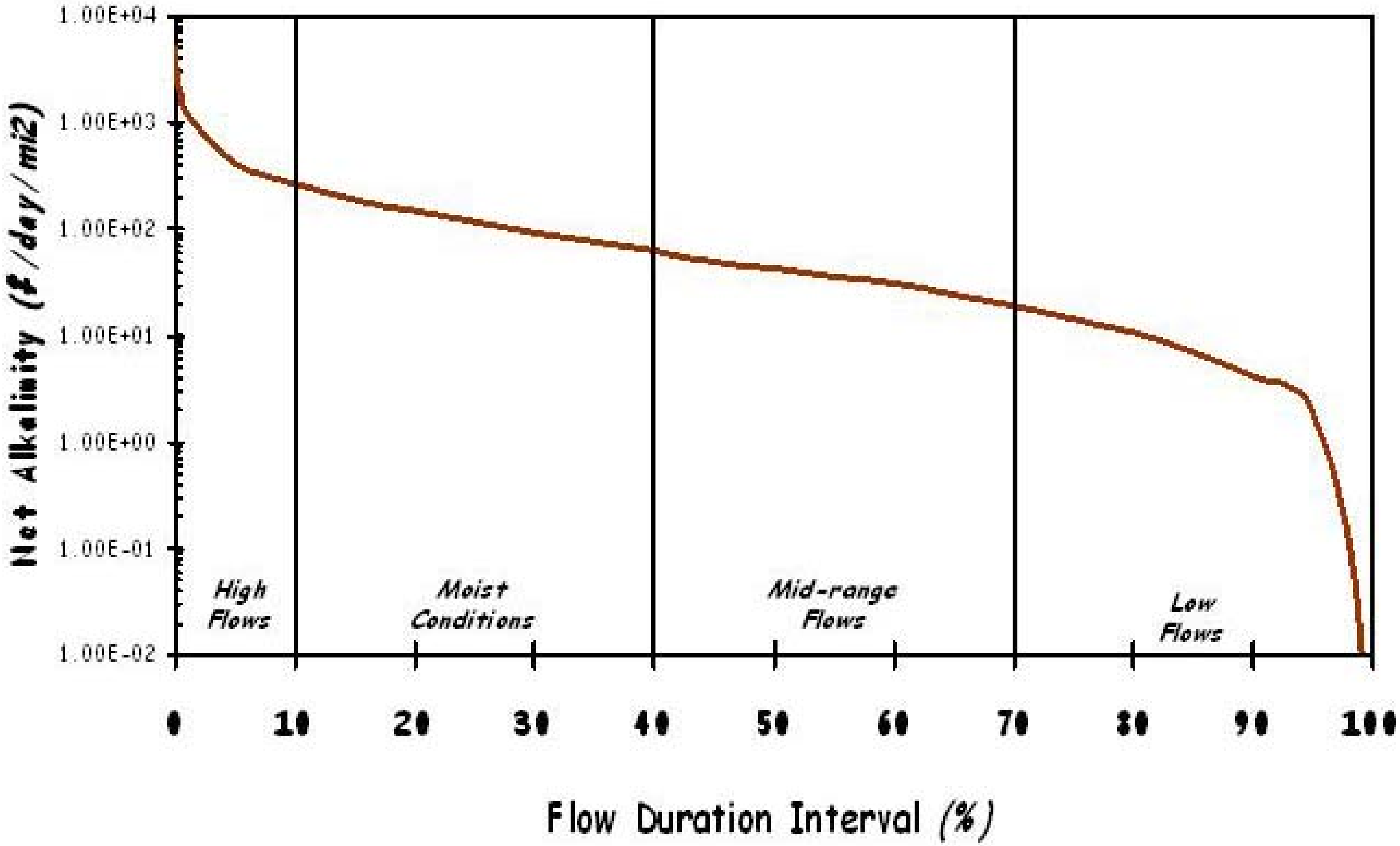

Figure E-2 Target Net Alkalinity Load Duration Curve (semi-log-scale)

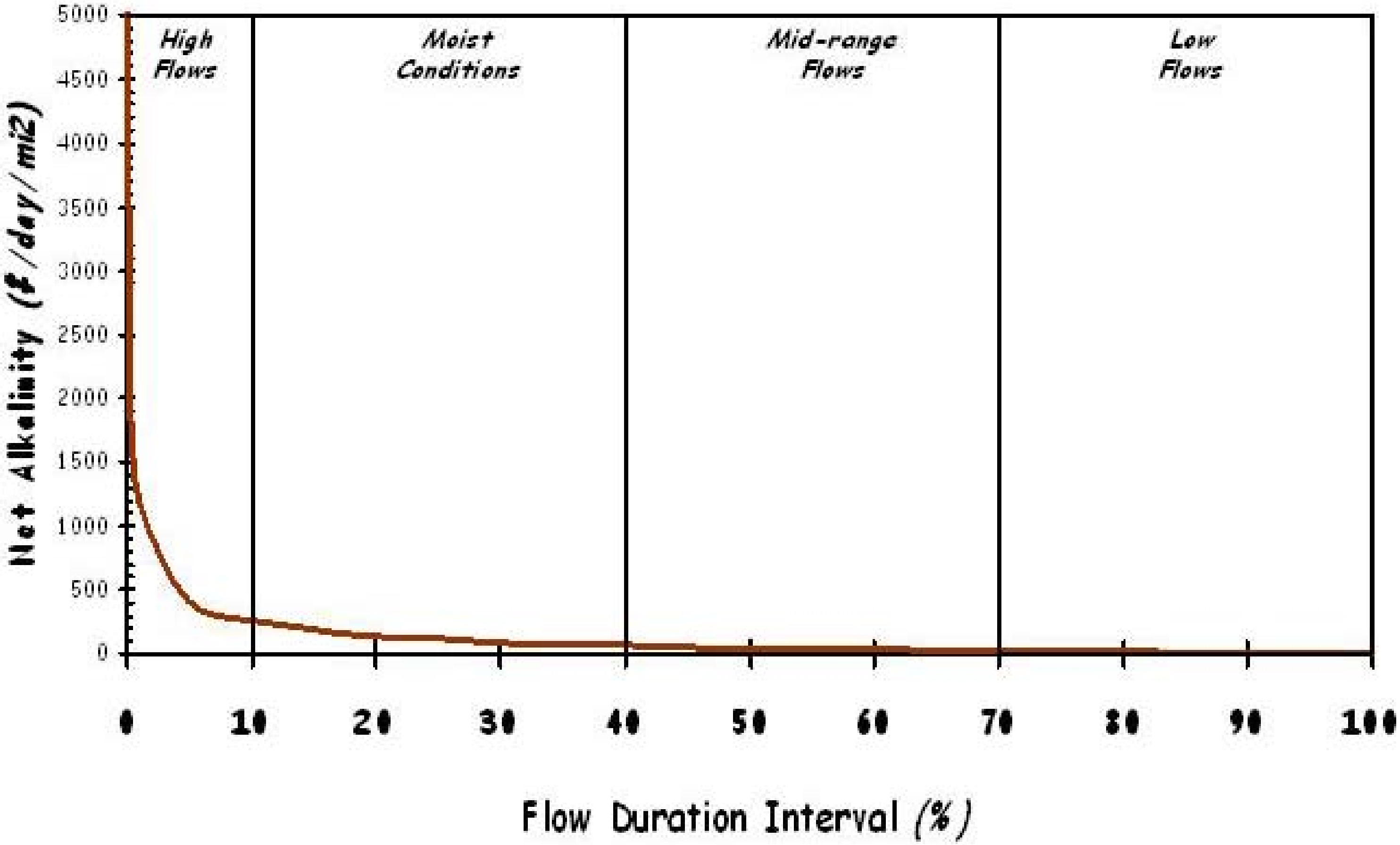

Figure E-3 Target Net Alkalinity Load Duration Curve (non-log scale)

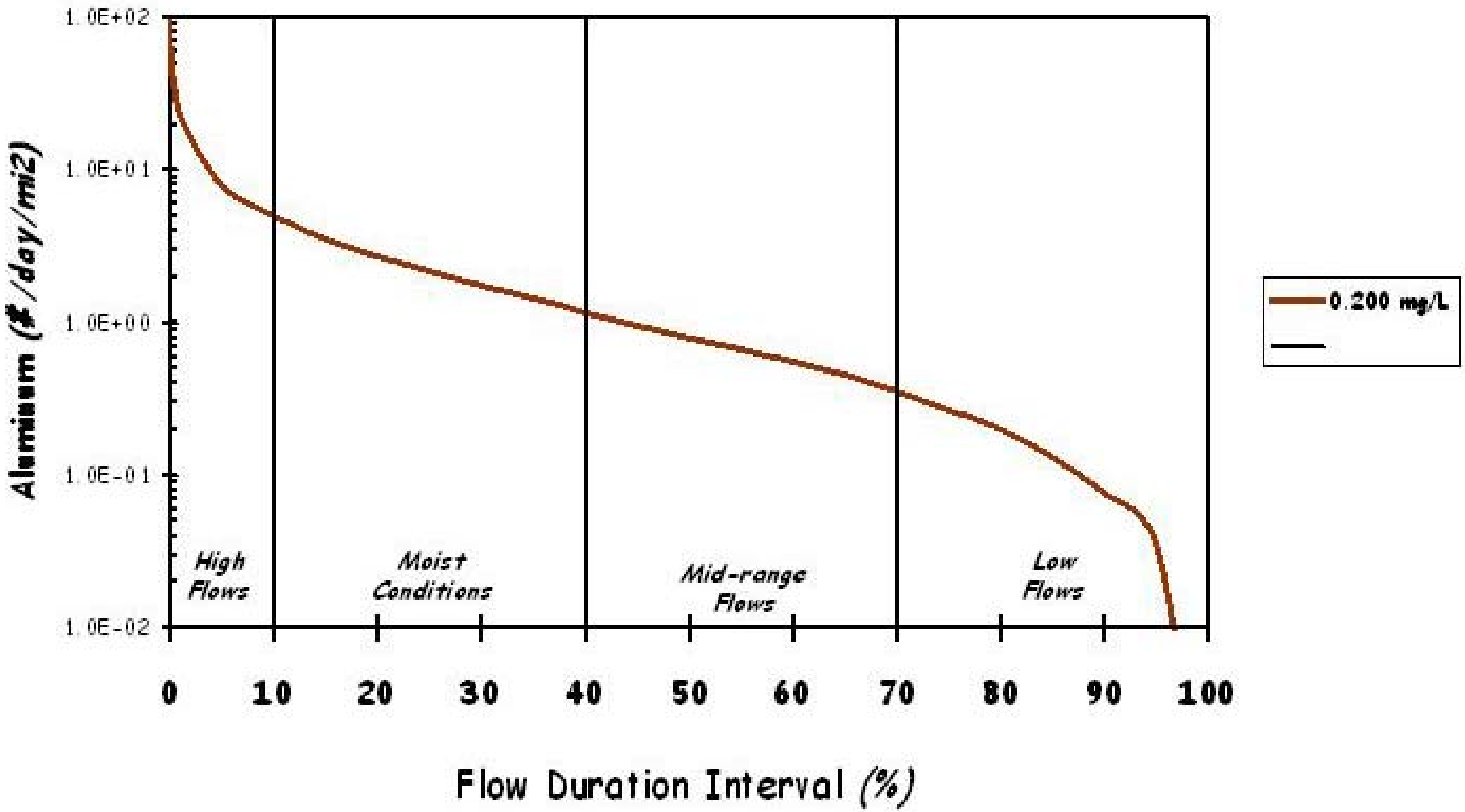

Figure E-4 Target Aluminum Load Duration Curve

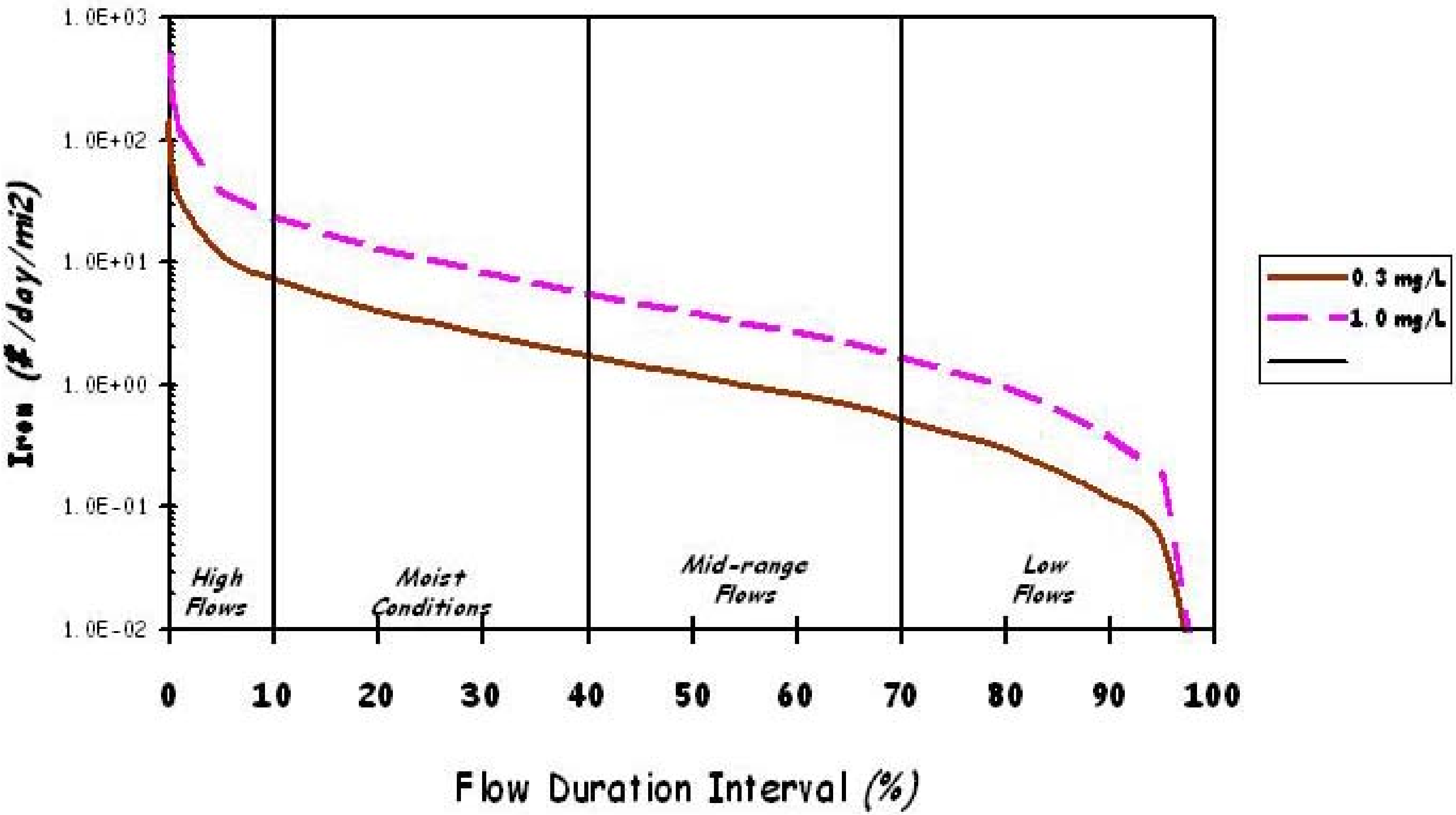

Figure E-5 Target Iron Load Duration Curve

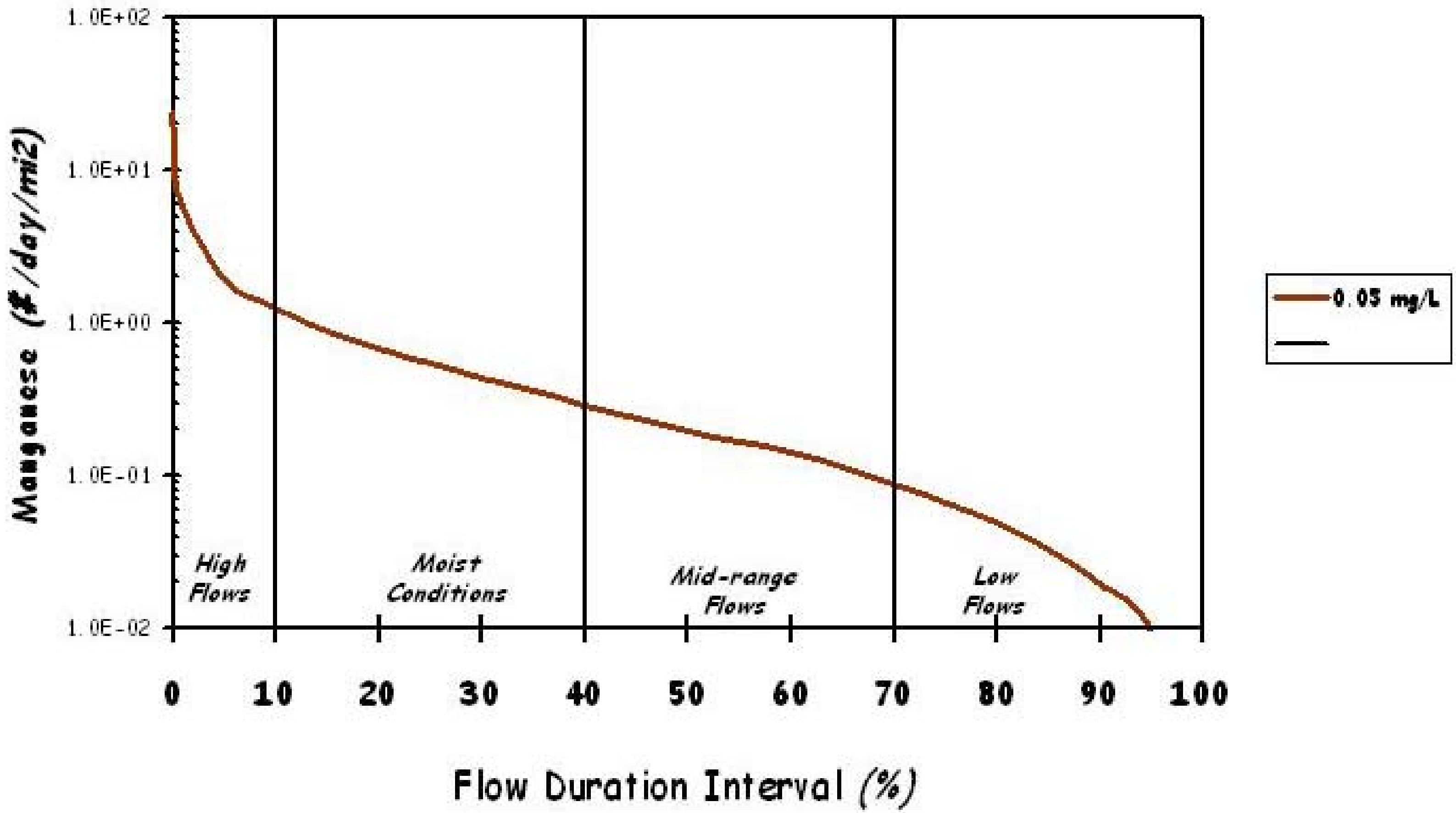

Figure E-6 Target Manganese Load Duration Curve

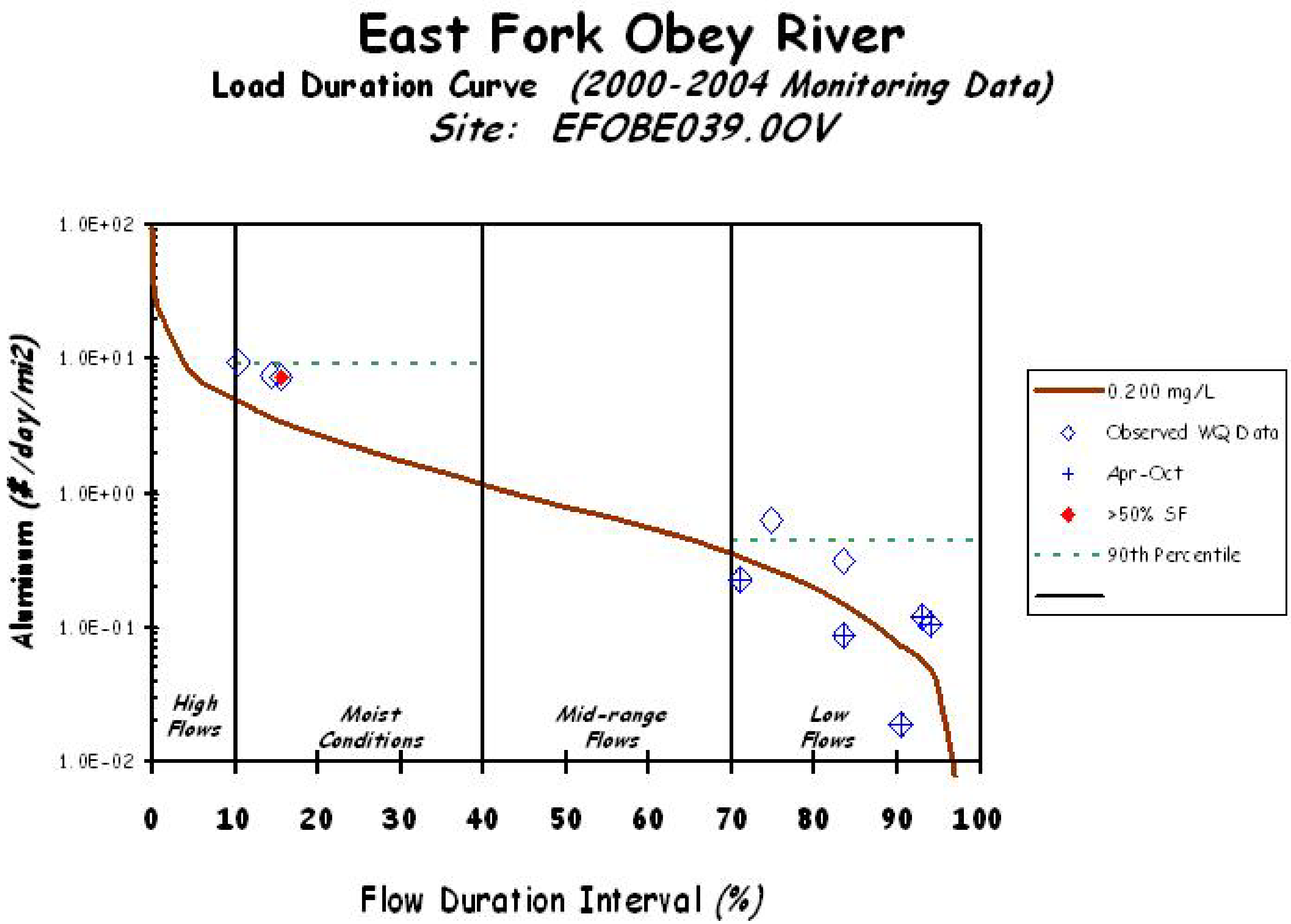

Figure E-7 Aluminum Load Duration Curve for East Fork Obey River at Mile 39.0

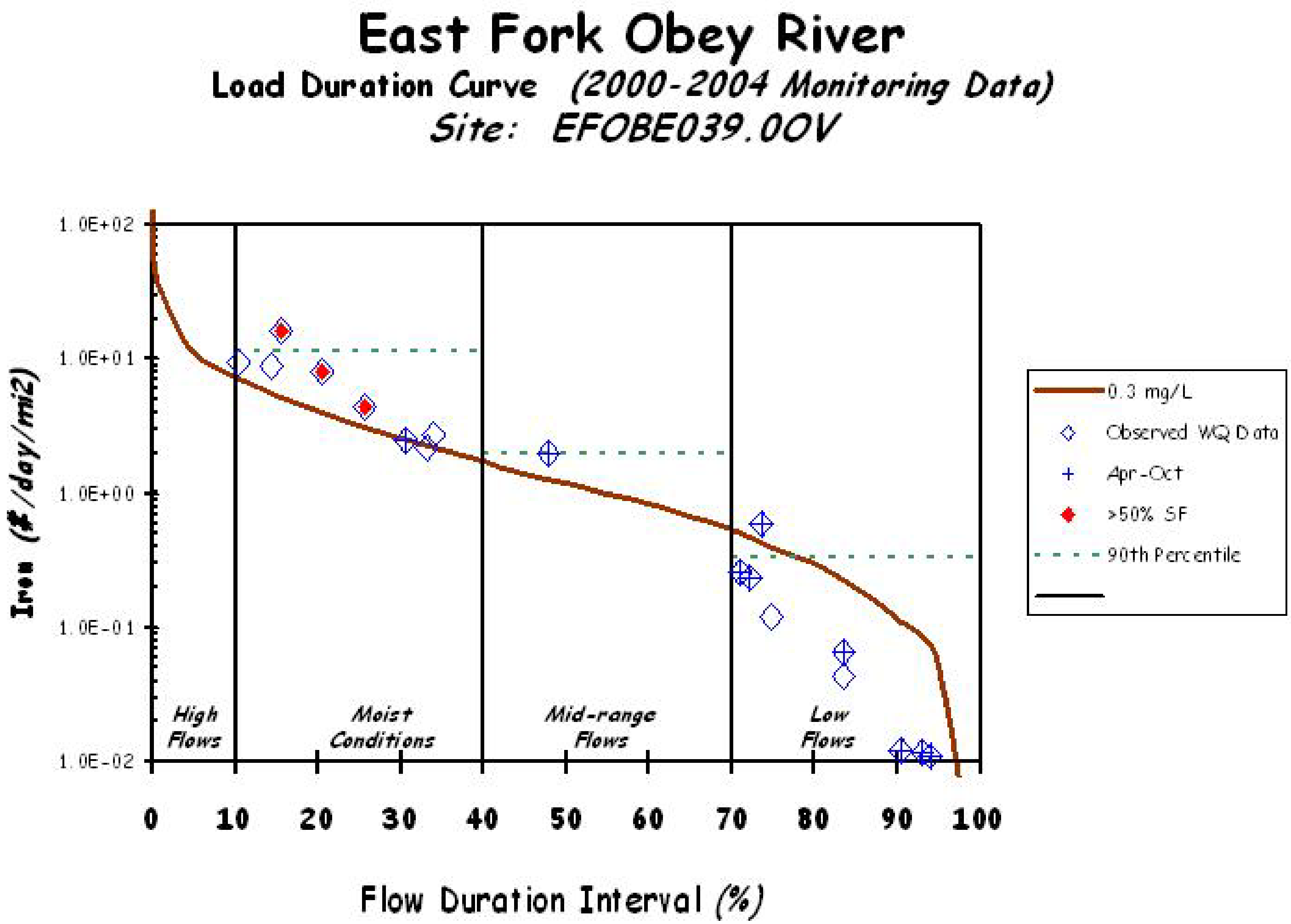

Figure E-8 Iron Load Duration Curve for East Fork Obey River at Mile 39.0

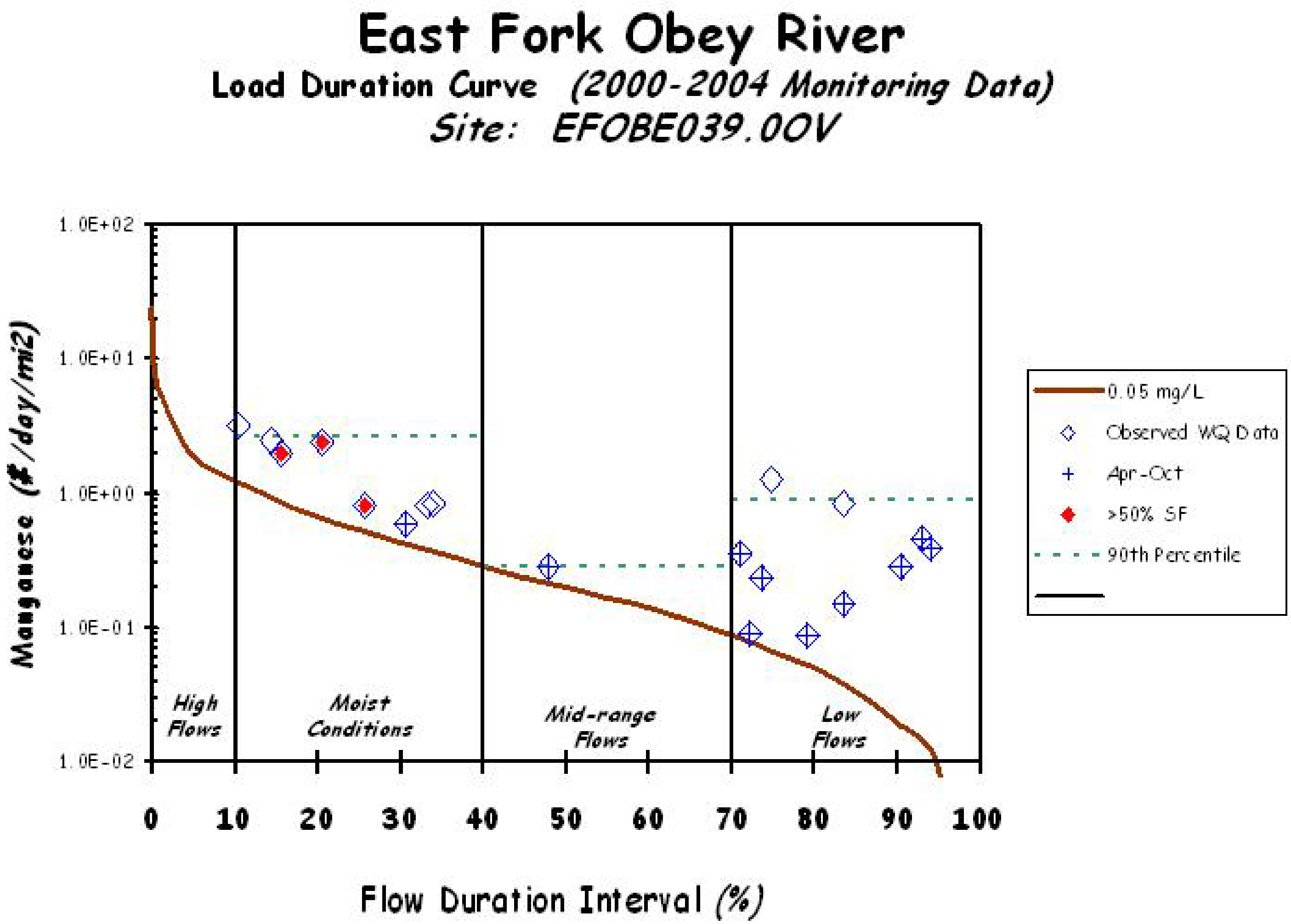

Figure E-9 Manganese Load Duration Curve for East Fork Obey River at Mile 39.0

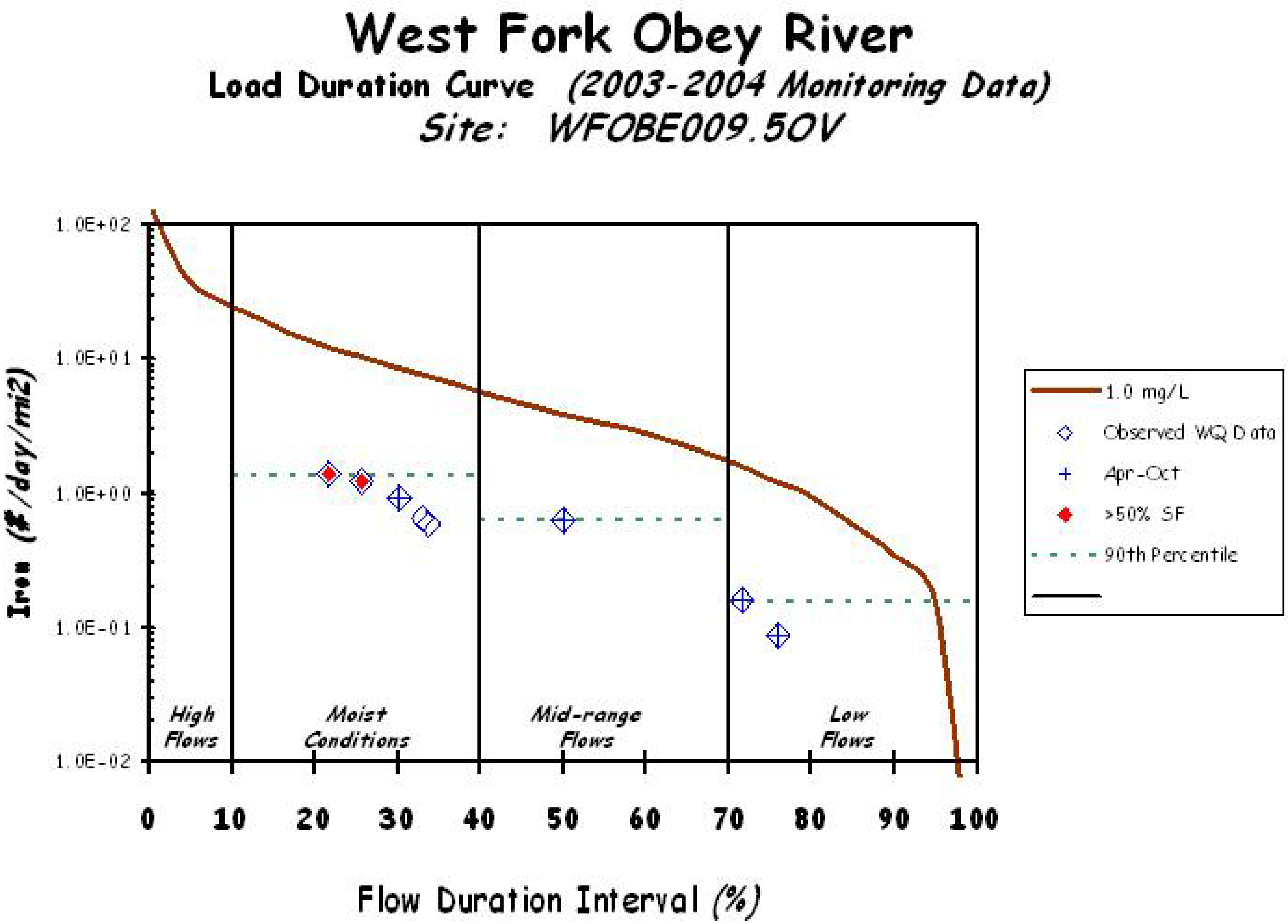

Figure E-10 Iron Load Duration Curve for West Fork Obey River at Mile 9.5

Table E-1. Aluminum Load Calculations for East Fork Obey River – Mile 39.0

Sample	Flow		PDFE[a]	Aluminum Concentration		Required Reduction[b]	
						to Target	to Target - MOS
Date	(cfs)	(cfs/mi^2)	(%)	(μg/L)	(lbs/day/mi^2)	(%)	(%)
7/11/00	6.71	0.198	79.2				
8/15/00	2.37	0.070	90.4	50	0.02	NR	NR
9/20/00	1.40	0.041	94.0	471	0.11	57.5	61.8
10/17/00	1.63	0.048	93.0	462	0.12	56.7	61.0
11/15/00	4.88	0.144	83.5	405	0.31	50.6	55.6
12/12/00	8.38	0.247	74.9	468	0.62	57.3	61.5
1/23/01	116.49	3.436	14.4	410	7.60	51.2	56.1
2/21/01	151.86	4.479	10.4	392	9.47	49.0	54.1
3/21/01	107.34	3.166	15.7	431	7.36	53.6	58.2
5/17/01	4.81	0.142	83.6	115	0.09	NR	NR
6/20/01	10.40	0.307	71.1	139	0.23	NR	NR
12/10/03	82.92	2.446	20.6				
1/13/04	47.85	1.412	33.3				
2/17/04	46.67	1.377	34.0				
3/17/04	65.34	1.927	25.8				
4/19/04	53.32	1.573	30.6				
5/18/04	8.93	0.264	73.7				
6/23/04	26.92	0.794	47.9				
8/17/04	9.59	0.283	72.3				
90th Percentile Concentration				**468**		**57.3**	**61.6**
Note:	NR = No Reduction Required						
a	Percent of Days Flow Is Exceeded						
b	Reductions for individual samples (shaded area) are included for reference only.						

Table E-2. Iron Load Calculations for East Fork Obey River – Mile 39.0

Sample	Flow		PDFE[a]	Iron Concentration		Required Reduction[b]	
						to Target	to Target - MOS
Date	(cfs)	(cfs/mi^2)	(%)	(μg/L)	(lbs/day/mi^2)	(%)	(%)
7/11/00	6.71	0.198	79.2				
8/15/00	2.37	0.070	90.4	32	0.01	NR	NR
9/20/00	1.40	0.041	94.0	50	0.01	NR	NR
10/17/00	1.63	0.048	93.0	45	0.01	NR	NR
11/15/00	4.88	0.144	83.5	56	0.04	NR	NR
12/12/00	8.38	0.247	74.9	90	0.12	NR	NR
1/23/01	116.49	3.436	14.4	484	8.97	38.0	44.2
2/21/01	151.86	4.479	10.4	396	9.57	24.2	31.8
3/21/01	107.34	3.166	15.7	955	16.31	68.6	71.7
5/17/01	4.81	0.142	83.6	87	0.07	NR	NR
6/20/01	10.40	0.307	71.1	158	0.26	NR	NR
12/10/03	82.92	2.446	20.6	605	7.98	50.4	55.4
1/13/04	47.85	1.412	33.3	284	2.16	NR	4.9
2/17/04	46.67	1.377	34.0	370	2.75	18.9	27.0
3/17/04	65.34	1.927	25.8	426	4.43	29.6	36.6
4/19/04	53.32	1.573	30.6	297	2.52	NR	9.1
5/18/04	8.93	0.264	73.7	423	0.60	29.1	36.2
6/23/04	26.92	0.794	47.9	461	1.97	34.9	41.4
8/17/04	9.59	0.283	72.3	152	0.23	NR	NR
90th Percentile Concentration				**520**		**42.3**	**48.1**
Note:	NR = No Reduction Required						
a	Percent of Days Flow Is Exceeded						
b	Reductions for individual samples (shaded area) are included for reference only.						

Table E-3. Manganese Load Calculations for East Fork Obey River – Mile 39.0

Sample	Flow		PDFE[a]	Manganese Concentration		Required Reduction[b]	
						to Target	to Target - MOS
Date	(cfs)	(cfs/mi^2)	(%)	(μg/L)	(lbs/day/mi^2)	(%)	(%)
7/11/00	6.71	0.198	79.2	82	0.09	39.0	45.1
8/15/00	2.37	0.070	90.4	760	0.29	93.4	94.1
9/20/00	1.40	0.041	94.0	1730	0.39	97.1	97.4
10/17/00	1.63	0.048	93.0	1750	0.45	97.1	97.4
11/15/00	4.88	0.144	83.5	1090	0.85	95.4	95.9
12/12/00	8.38	0.247	74.9	960	1.28	94.8	95.3
1/23/01	116.49	3.436	14.4	133	2.47	62.4	66.2
2/21/01	151.86	4.479	10.4	131	3.17	61.8	65.6
3/21/01	107.34	3.166	15.7	116	1.98	56.9	61.2
5/17/01	4.81	0.142	83.6	199	0.15	74.9	77.4
6/20/01	10.40	0.307	71.1	218	0.36	77.1	79.4
12/10/03	82.92	2.446	20.6	181	2.39	72.4	75.1
1/13/04	47.85	1.412	33.3	108	0.82	53.7	58.3
2/17/04	46.67	1.377	34.0	113	0.84	55.8	60.2
3/17/04	65.34	1.927	25.8	78	0.81	35.9	42.3
4/19/04	53.32	1.573	30.6	70	0.59	28.6	35.7
5/18/04	8.93	0.264	73.7	168	0.24	70.2	73.2
6/23/04	26.92	0.794	47.9	67	0.29	25.4	32.8
8/17/04	9.59	0.283	72.3	59	0.09	15.3	23.7
90th Percentile Concentration				**1218**		**95.9**	**96.3**
Note:	NR = No Reduction Required						
a	Percent of Days Flow Is Exceeded						
b	Reductions for individual samples (shaded area) are included for reference only.						

Table E-4. Iron Load Calculations for West Fork Obey River – Mile 9.5

Sample	Flow		PDFE[a]	Iron Concentration		Required Reduction[b]	
						to Target	to Target - MOS
Date	(cfs)	(cfs/mi^2)	(%)	(µg/L)	(lbs/day/mi^2)	(%)	(%)
12/10/03	161.08	2.352	21.7	111	1.41	NR	NR
1/13/04	97.57	1.424	33.0	84	0.65	NR	NR
2/17/04	94.78	1.384	33.8	79	0.59	NR	NR
3/17/04	133.03	1.942	25.7	118	1.24	NR	NR
4/19/04	108.71	1.587	30.3	109	0.93	NR	NR
5/18/04	15.29	0.223	76.1	73	0.09	NR	NR
6/23/04	49.66	0.725	50.0	164	0.64	NR	NR
8/17/04	19.65	0.287	71.6	105	0.16	NR	NR
90th Percentile Concentration				132		NR	NR
Note:	NR = No Reduction Required						
a	Percent of Days Flow Is Exceeded						
b	Reductions for individual samples (shaded area) are included for reference only.						

Table E-5. TMDLs, WLAs, & LAs expressed as daily loads for Impaired Waterbodies in the Obey River Watershed (HUC05130105)

Impaired Waterbody Name	Impaired Waterbody ID	Constituent	PLRG	TMDL	Explicit MOS	WLAs	LAs
			[%]	[lbs/day]	[lbs/day]	[lbs/day]	[lbs/day/ac]
Cub Creek	TN05130105015 – 0300	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	1.56 x 10^{-2} x Q
		Iron	NA	5.38 x Q	0.538 x Q	NA	1.30 x 10^{-3} x Q
West Fork Obey River	TN05130105015 – 2000	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	1.33 x 10^{-3} x Q
		Iron	NR	5.38 x Q	0.538 x Q	NA	1.10 x 10^{-4} x Q
Big Laurel Creek	TN05130105019 – 1100	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	7.20 x 10^{-3} x Q
		Iron	NA	5.38 x Q	0.538 x Q	NA	6.00 x 10^{-4} x Q
Little Laurel Creek	TN05130105019 – 1110	Net Alkalinity	NA	58.1 x Q	NA[b]	NA	2.39 x 10^{-2} x Q
		Iron	NA	5.38 x Q	0.538 x Q	NA	1.99 x 10^{-3} x Q
Big Piney Creek	TN05130105019 – 1200	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	6.11 x 10^{-3} x Q
East Fork Obey River	TN05130105019 – 2000	Net Alkalinity	NA	58.1 x Q	NA[a]	58.1 x Q_2	(5.36 x 10^{-4} x Q) – (5.36 x 10^{-4} x Q_2)
		Iron	42.3	1.61 x Q	0.161 x Q	16.1 x Q_2	(1.34 x 10^{-5} x Q) – (1.49 x 10^{-4} x Q_2)
		Manganese	95.9	0.269 x Q	2.69 x 10^{-2}x Q	10.8 x Q_2	(2.23 x 10^{-6} x Q) – (9.93 x 10^{-5} x Q_2)
		Aluminum	57.3	1.076 x Q	0.1076 x Q	NA	4.46 x 10^{-5} x Q
East Fork Obey River	TN05130105019 – 3000	Net Alkalinity	NA	58.1 x Q	NA[a]	NA	2.68 x 10^{-3} x Q
		Iron	42.3	1.61 x Q	0.161 x Q	NA	6.69 x 10^{-5} x Q
		Manganese	95.9	0.269 x Q	2.69 x 10^{-2}x Q	NA	1.12 x 10^{-5} x Q
		Aluminum	57.3	1.076 x Q	0.1076 x Q	NA	4.46 x 10^{-5} x Q

Notes: NA = Not Applicable.
NR = No Reduction Required
PLRG = Percent Load Reduction Goal
Q = Mean Daily In-stream Flow (cfs).
Q_2 = Mean Daily Flow (cfs) from Permitted Point Sources (combined)

a. For development of net alkalinity TMDLs, an implicit MOS was incorporated through the use of conservative modeling assumptions (see Section 7.5).

APPENDIX F

Hydrodynamic Modeling Methodology

F.1 Model Selection

The Loading Simulation Program C++ (LSPC) was selected for TMDL analyses of pH- and metal-impaired waters in the Obey River watershed. LSPC is a watershed model capable of performing flow routing through stream reaches. LSPC is a dynamic watershed model based on the Hydrologic Simulation Program – Fortran (HSPF).

F.2 Model Set Up

The Obey River watershed was delineated into subwatersheds in order to facilitate model hydrologic calibration. Boundaries were constructed so that subwatershed “pour points” coincided with HUC-12 delineations, impaired waterbodies, and water quality monitoring stations. Watershed delineation was based on the NHD stream coverage and Digital Elevation Model (DEM) data. This discretization facilitates simulation of daily flows at water quality monitoring stations.

Several computer-based tools were utilized to generate input data for the LSPC model. The Watershed Characterization System (WCS), a geographic information system (GIS) tool, was used to display, analyze, and compile available information to support hydrology model simulations for the Obey River subwatersheds. This information includes land use categories, point source dischargers, soil types and characteristics, population data (human and livestock), and stream characteristics.

An important factor influencing model results is the precipitation data contained in the meteorological data file used in the simulation. Weather data from the Knoxville meteorological station were available for the time period from January 1980 through December 2005. Meteorological data for a selected 11-year period were used for all simulations. The first year of this period was used for model stabilization with simulation data from the subsequent 10-year period (10/1/95 – 9/30/05) used for TMDL analysis.

F.3 Model Calibration

Hydrologic calibration of the watershed model involves comparison of simulated streamflow to historic streamflow data from U.S. Geological Survey (USGS) stream gaging stations for the same period of time. A USGS continuous record station located in the South Fork Cumberland Watershed with a sufficiently long and recent historical record was selected as a basis of the hydrology calibration. The USGS station was selected based on similarity of drainage area, Level IV ecoregion, land use, and topography. The calibration involved comparison of simulated and observed hydrographs until statistical stream volumes and flows were within acceptable ranges as reported in the literature (Lumb, et al., 1994).

Initial values for hydrologic variables were taken from an EPA developed default data set. During the calibration process, model parameters were adjusted within reasonable constraints until acceptable agreement was achieved between simulated and observed streamflow. Model parameters adjusted include: evapotranspiration, infiltration, upper and lower zone storage, groundwater storage, recession, losses to the deep groundwater system, and interflow discharge.

The results of the hydrologic calibration for New River at New River, Tennessee, USGS Station 03408500, are shown in Table F-1 and Figures F-1 and F-2.

Table F-1 Hydrologic Calibration Summary: New River, USGS 03408500

				381.96	sq. m
	Simulation Name:	3408500	**Simulation Period:**		
		New River @ New River	**Watershed Area (ac):**	244456.93	
	Period for Flow Analysis				
	Begin Date:	**07/01/98**	**Baseflow PERCENTILE:**	2.5	
	End Date:	**06/30/04**	*Usually 1%-5%*		
	Total Simulated In-stream Flow:	**130.26**	Total Observed In-stream Flow:	**137.03**	
	Total of highest 10% flows:	**71.67**	Total of Observed highest 10% flows:	**74.48**	
	Total of lowest 50% flows:	**8.23**	Total of Observed Lowest 50% flows:	**7.91**	
	Simulated Summer Flow Volume (months 7-9):	**15.86**	Observed Summer Flow Volume (7-9):	**10.63**	
	Simulated Fall Flow Volume (months 10-12):	**18.27**	Observed Fall Flow Volume (10-12):	**19.77**	
	Simulated Winter Flow Volume (months 1-3):	**60.40**	Observed Winter Flow Volume (1-3):	**65.07**	
	Simulated Spring Flow Volume (months 4-6):	**35.73**	Observed Spring Flow Volume (4-6):	**41.55**	
	Total Simulated Storm Volume:	**128.87**	Total Observed Storm Volume:	**136.42**	
	Simulated Summer Storm Volume (7-9):	**15.52**	Observed Summer Storm Volume (7-9):	**10.48**	
	Errors (Simulated-Observed)		*Recommended Criteria*	Last run	
	Error in total volume:	**-4.94**	10		
	Error in 50% lowest flows:	**4.04**	10		
	Error in 10% highest flows:	**-3.78**	15		
***	Seasonal volume error - Summer:	**49.15**	30		
	Seasonal volume error - Fall:	**-7.63**	30		
	Seasonal volume error - Winter:	**-7.18**	30		
	Seasonal volume error - Spring:	**-14.00**	30		
	Error in storm volumes:	**-5.54**	20		
	Error in summer storm volumes:	**48.04**	50		

Criteria for Median Monthly Flow Comparisons	
Lower Bound (Percentile):	25
Upper Bound (Percentile):	75

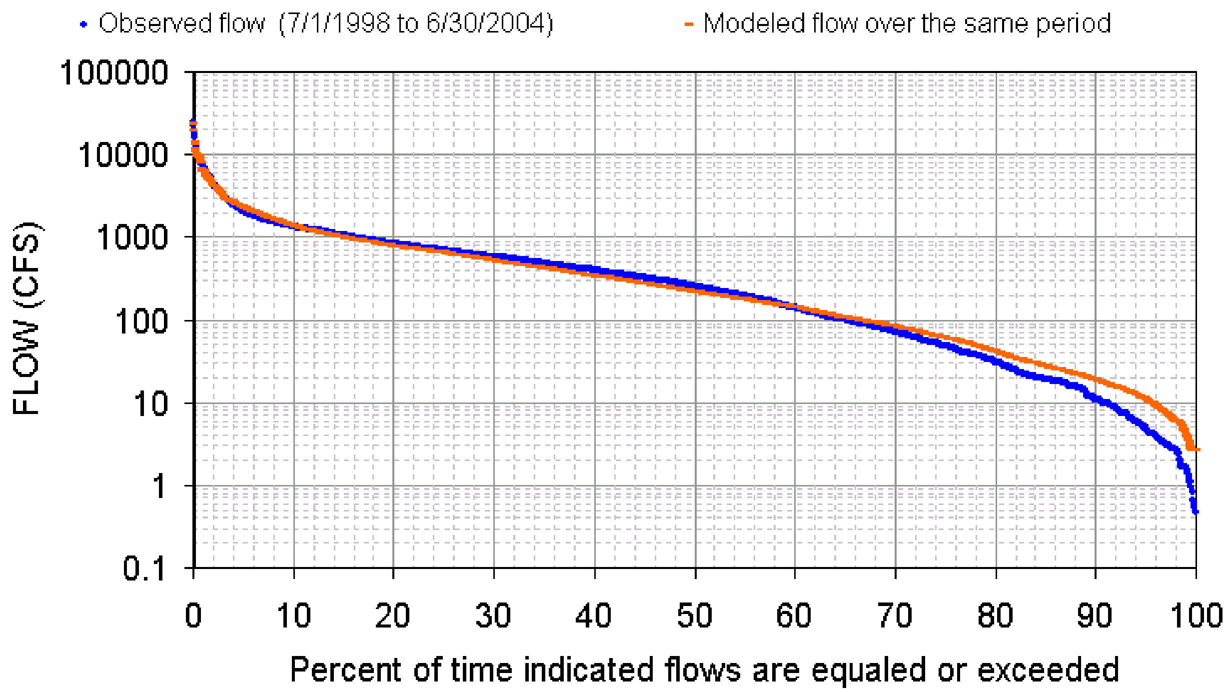

Figure F-1. Hydrologic Calibration: New River, USGS 03408500

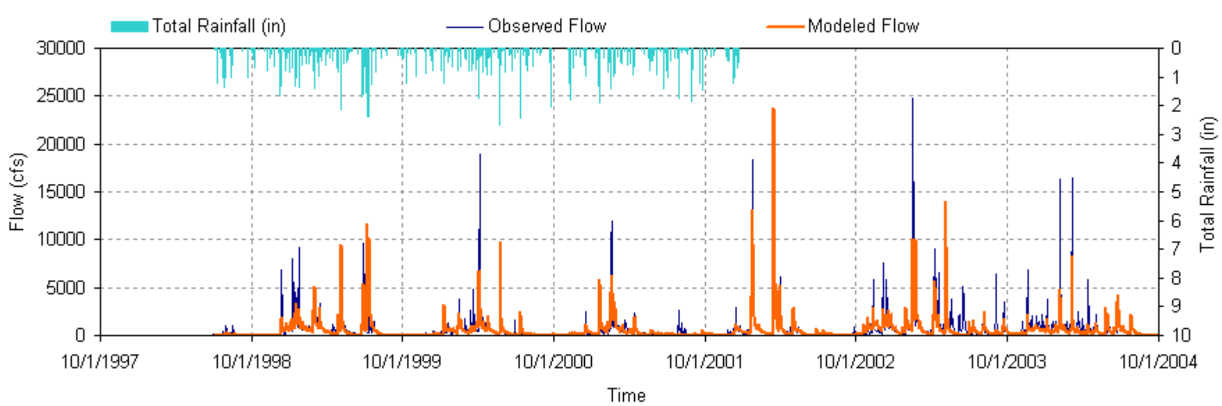

Figure F-2. 7-Year Hydrologic Comparison: New River, USGS 03408500

APPENDIX G

Public Notice Announcement

STATE OF TENNESSEE
DEPARTMENT OF ENVIRONMENT AND CONSERVATION
DIVISION OF WATER POLLUTION CONTROL

PUBLIC NOTICE OF AVAILABILITY OF PROPOSED TOTAL MAXIMUM DAILY LOADS (TMDLs) FOR pH and METALS IN OBEY RIVER WATERSHED (HUC 05130105), TENNESSEE

Announcement is hereby given of the availability of Tennessee's proposed Total Maximum Daily Loads (TMDLs) for pH and metals in the Obey River watershed, located in middle and eastern Tennessee. Section 303(d) of the Clean Water Act requires states to develop TMDLs for waters on their impaired waters list. TMDLs must determine the allowable pollutant load that the water can assimilate, allocate that load among the various point and nonpoint sources, include a margin of safety, and address seasonality.

Several waterbodies are listed on Tennessee's Final 2006 303(d) list as not supporting designated use classifications due, in part, to low pH and metals associated with abandoned mines. The TMDL utilizes Tennessee's general water quality criteria, net alkalinity (as $CaCO_3$) as a surrogate for pH, USGS continuous record station flow data, in-stream water quality monitoring data, a calibrated dynamic water quality model, load duration curves, and an appropriate Margin of Safety (MOS) to establish loadings of net alkalinity (as $CaCO_3$) which will result in the attainment of water quality standards for pH.

The proposed Obey River pH and Metals TMDLs may be downloaded from the Department of Environment and Conservation website:

http://www.state.tn.us/environment/wpc/tmdl/

Technical questions regarding these TMDLs should be directed to the following members of the Division of Water Pollution Control staff:

Vicki S. Steed, P.E., Watershed Management Section
Telephone: 615-532-0707

Sherry H. Wang, Ph.D., Watershed Management Section
Telephone: 615-532-0656

Persons wishing to comment on the proposed TMDLs are invited to submit their comments in writing no later than February 11, 2008 to:

Division of Water Pollution Control
Watershed Management Section
7th Floor, L & C Annex
401 Church Street
Nashville, TN 37243-1534

All comments received prior to that date will be considered when revising the TMDL for final submittal to the U.S. Environmental Protection Agency.

The TMDL and supporting information are on file at the Division of Water Pollution Control, 6th Floor, L & C Annex, 401 Church Street, Nashville, Tennessee. They may be inspected during normal office hours. Copies of the information on file are available on request.